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Issues in NASA Program and Project Management

A Collection of Papers on Aerospace Management Issues

National Aeronautics and Space Administration — Spring 1995

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The "One-Pager": Methodology and Application

by Tony E. Schoenfelder

Today's NASA program/project managers must operate within an environment of increasing volatility, uncertainty and seemingly contradictory goals. With Congress intent upon cutting federal discretionary spending, programs may be slipped, reduced in content or scope and/or redesigned, perhaps within the space of a single fiscal year. The litany of faster, better, cheaper implies a willingness to accept greater technical risk, yet NASA may not be allowed to fail, thereby making it extremely difficult to achieve the cost, schedule and technical goals set for programs. Certainly, the magnitude of cost and schedule overruns experienced by past NASA programs will not be tolerated in the future.

NASA program and project managers need a system that will facilitate timely, accurate top-down program/project assessments required to establish and/or assess the program's baseline plan, determine progress against the plan and assess planning alternatives. It must operate effectively and efficiently under constantly changing conditions. Existing NASA systems often fail to satisfy these requirements. Scheduling and performance measurement systems are very detailed and extensive and generate vast amounts of data, but rarely in a form or format that is conducive to providing timely visibility into today's programs. This, coupled with the NASA project management community's great appetite for detail, tends to choke the system and prohibit quick action. In addition, contractual arrangements between NASA and its contractors often discourage the contractor from providing accurate long range budget planning, as there is no incentive offered to provide the occasional bad news.

The One-Pager is a single chart that presents an integrated cost, schedule and content (metrics) display for a selected end item. It was designed to help management focus on key cost, schedule and technical drivers and serve as a common basis for communications. It is simple in concept and appearance, is produced using a consistent methodology, focuses at the subsystem or key ORU level, is done in the context of a hardware /integration/test "backbone," captures only the important "nuggets," and places its emphasis on "programmatics," which are defined here as the interplay and relationship between the cost, schedule and technical aspects of a program.

Figure 1 is an example of a one-pager which reflects the baseline plan for a new development nickel hydrogen battery as of December 1992. While it is not as complete (in terms of cost and metrics) as might be desired, it nonetheless provides an excellent example of the type and amount of information contained within a properly constructed one-pager.

A little background is in order before discussing Figure 1. The nickel-hydrogen battery comprises four basic components: the cells, the battery signal conditioning and control module (BSCCM), an enclosure, and some

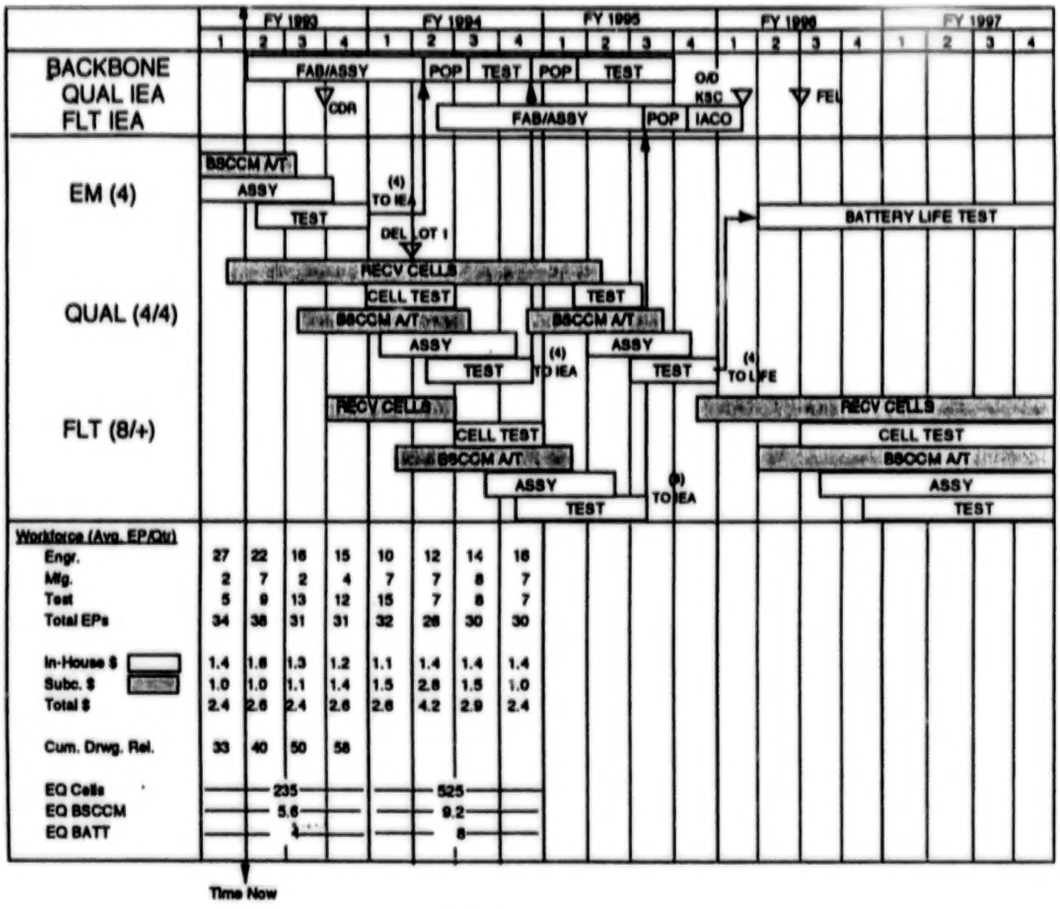

Figure 1. Battery One-Pager 12/92

parts. The one-pager in Figure 1 focuses on the cells and the BSCCM (the most complex and costly components), and tracks the engineering models, the qualification units and the flight hardware for each. Engineering models (EM) are often referred to as form-fit-and-function articles, and with the exception of certain environmental and space-rated parts requirements, conform to actual flight specifications (volume, shape and weight constraints, power utilization limitations, etc.). The results of engineering model testing feed into the critical design review (CDR) process. The qualification or "qual" unit (sometimes referred to as the prototype unit) is the first unit built to all flight specification requirements; it also undergoes extensive testing. In crewed programs, this unit is not usually flown. Flight hardware is the actual unit flown. The unit not only meets form, fit and function criteria, but also is constructed of space-rated parts. In uncrewed programs, a protoflighting approach is often used, whereby the qualification unit is refurbished and flown, thus avoiding the production of another flight unit.

The "backbone" or multi-system hardware/integration/test program, which provides a context for the battery hardware, is shown

at the top of the one-pager in Figure 1. This program dictates that, after individual testing, engineering model hardware from several different systems will be used to populate half of the Integrated Equipment Assembly (IEA) qual unit. The IEA then undergoes a series of tests designed to determine whether the integrated hardware from different systems will play together properly.

At the completion of these tests, qual hardware from the different systems will populate the other half of the qual IEA and a series of integrated tests are again conducted. The final piece of the "backbone" shows flight hardware populating the flight IEA unit in preparation for Integration, Assembly & Checkout (IACO). These multi-system hardware/integration/test programs govern, to a considerable degree, both the fidelity (engineering model, qual unit, or flight unit) and delivery dates of hardware and, as we shall see, play an important role in the overall risk profile of the program.

Finally, shaded schedule activity bars refer to subcontractors, while unshaded activity bars refer to in-house.

Now examine Figure 1, starting at the top left. As of T_{Now}, the cell EM tests have been completed, the BSCCM EM tests are underway (with four months remaining until completion), but the battery EM tests have not yet commenced. Note that CDR is scheduled to occur three months before the completion of battery engineering model testing. Since the results of engineering model testing feed into the CDR process, we should be aware that the CDR may not be as complete as it could be, thereby introducing technical risk and/or the possibility that a delta CDR might have to be conducted.

Battery EM tests are completed prior to beginning the assembly of battery qual units, and although there is a bit of overlap between the completion of the first battery qual tests and the assembly of the flight units, the overlap is acceptable and the risk is deemed low. The time between the completion of the EM tests and the first flight article delivery (to the flight IEA) is a bit over eighteen months. Historically, this time period has been closer to twenty-four months, so the intent to accomplish delivery much earlier should be viewed with moderate concern.

The IEA EM testing is scheduled to be completed at the same time as the first battery set qual tests are to be completed and midway through the assembly of the battery flight unit. This means that if the battery EM contains some error such that it does not play properly with other system hardware in an integrated test mode, that error is also present in the qual and flight hardware. Errors that occur at this stage of the design/production cycle may cost as much as ten times more to correct than errors detected much earlier.

The first battery flight article is scheduled to be delivered two months prior to completion of the IEA qual tests, and the fully integrated IEA flight article is due on-dock at KSC only five months after completion of the IEA qual tests. There is clearly no schedule slack available to correct any errors in the battery that might be detected through integrated testing of the IEA. This schedule

should be viewed overall with a high level of concern. However, given that the multi-system integrated testing schedule seems somewhat out of phase with the battery's development schedule, the importance of the integrated testing with respect to the battery should be investigated.

Turning our attention to the cost and metrics section of the battery one-pager in Figure 1, note that the engineering work force peaked at 27 EPs in the quarter prior to T_{Now}, and is scheduled to continue decreasing to 60 percent of peak at CDR and 37 percent of peak at the start of battery qual assembly. This decrease in the engineering work force at a time when engineering should be at or near its peak should be viewed with a high level of concern. The risk is one of additional costs to sustain engineering at higher levels and/or of additional schedule to complete the engineering job. The manufacturing work force is at 25 percent of its peak during the last quarter of the EM assembly, while the test work force is at 50 percent of its peak during the last quarter of qual testing. This is counter to what one might expect, and should be viewed with a high level of concern, as the reconciliation of this risk is liable to be either increased cost and/or additional schedule.

Finally, notice the equivalent units of subcontracted work and the dollars associated with them in FY93 and FY94. The plan shows that more than twice as many equivalent units of cells and twice as many equivalent batteries are to be produced in FY94 as in FY93, but for much less than twice the cost. Coupled with the probability that more engineering effort than anticipated will occur during FY93, there should be a moderate level of concern that the project will be unable to achieve the levels of production as planned.

One-pagers contain an impressive amount of information in a simple, comprehensible format. They also confer a number of benefits on users. They force a very disciplined analytical approach by both the people who construct them and those who use them. They promote a greater in-depth understanding as to how a program fits together, force everyone to focus at the same level, and communicate extremely well. If used to facilitate a replanning, the turnaround time is extremely low. If used to assess a baseline plan or determine progress against a plan, it yields an informed opinion, finding or observation, sets agenda items for management forums and focuses management's attention on the target area. Perhaps one of the most beneficial yields from the use of one-pagers is that engineers, analysts and management become attuned to programmatic issues and develop a "feel" for the program. (A "feel" for the program is defined as a personal knowledge base as to how various cost, schedule and technical aspects of a program play together such that one develops an intuitive understanding of how a change in one will affect the others.)

Perhaps the best way to further describe the discipline of the one-pager is to discuss how you would use the one-pager concept to build a baseline plan for a selected end-item. You will notice that at almost every step, you will be encouraged to "test" the data, to question whether what you see makes sense or meets your expectations. This promotes the kind

of in-depth understanding of the program that is required by the analyst and, ultimately, by the users of the one-pager.

Putting together a one-pager is not an easy job. It is assumed that anyone attempting to build one has a familiarity with work breakdown structures, is able to understand and use schedules, understands program logic and can lay out conceptual hardware flows, is well-versed in "programmatics" and program analysis and has experience with elements of cost.

The first thing you ought to do is become familiar with the project. Review the program/project plans to get a feel for end-items or deliverables, systems, subsystems and components, key project milestones, key risk areas, number of procurements and summary cost data. You will need assistance from project and engineering personnel in selecting critical items to include in one-pagers, so you ought to develop contacts and data sources that will facilitate an understanding of the top level technical issues and the overall risk profile. You must understand how the program/project schedules were developed and what the underlying assumptions were with respect to barlength, shifting, lead times, learning, analogies, smoothness/continuity, etc. Once you have determined these things, you should calibrate the overall risk inherent in the baseline schedule. This provides information that will be useful later on as you assess progress against the plan or contemplate a replanning activity.

Prior to selecting candidates for one-pagers, you should develop a hardware hierarchy tree for each system and identify the most critical components. The selection of candidates for one-pagers is based on the principle that management attention should be focused on major drivers, i.e., those definitive end items which exhibit one or more of the following characteristics: 1) high cost, 2) high technical risk, 3) high schedule risk and 4) key integration intersection.

There is generally a high correlation between risk (technical and schedule) and cost. A good rule of thumb to observe is that one-pagers should include content worth at least 65 percent or more of the total cost. Please note that ***who*** performs the work has no bearing on whether a system or subsystem is selected for a one-pager. In major development projects, 50 percent or more of the work may be subcontracted. Do ***not*** accept the premise that it is the prime contractor's job to worry about the subs, and that one-pagers are therefore unnecessary for subcontracted items. There may be pressure to convince you otherwise, but one of the most common problems experienced by project managers is an unforeseen growth in subcontractor estimates.

Deciding what ***not*** to include is perhaps the most difficult process. Since we are focusing management's attention on major drivers, minor products and processes should be reviewed on an exception basis only, and should not be included in a one-pager. The prime contractor's schedule book for a major space development contract ($100M to several billion dollars) may contain 500 to 1,000 pages. For a project of this size, no more than 20 one-pagers should be selected

for project-level management. Lower levels should have one-pagers for their respective areas of responsibility that tier into the 20.

After selecting an item for a one-pager, lay out a conceptual logic flow, focusing on the "backbone" concept, critical items and fidelity-to-fidelity relationships. The goal is to identify the major pieces of each item and how they flow together.

The next step in the preparation of a one-pager is selecting the schedule items. Your selection should emphasize the hardware development process, the hardware hierarchy and the fidelity of the hardware. It is critically important to use a schedule template which possesses the following characteristics:

1. Conciseness—As discussed earlier, the one-pager concept requires that you reduce the 500 to 1,000 pages of a major space systems project schedule book to 20 or fewer one-pagers. An additional target is to represent schedule, cost and metric data for each one-pager in 20 lines. Figure 2 shows an example of how 20 lines of data might be allocated.

2. Standardization—Select a common set of activities and milestones that can be applied to all systems, subsystems and components.

3. "Relatability"—Select activities and milestones that can be related to cost, work force levels and metrics.

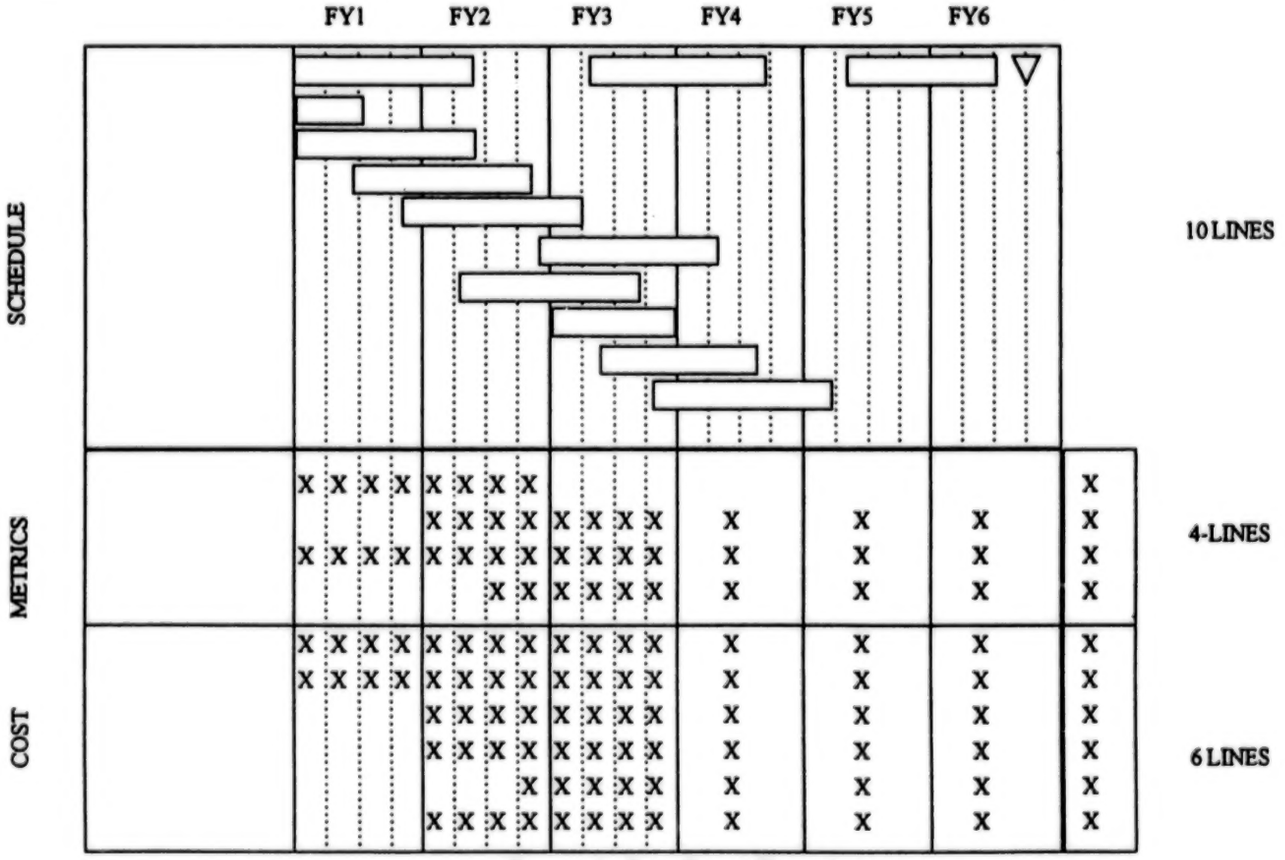

Figure 2. One-Pager Template

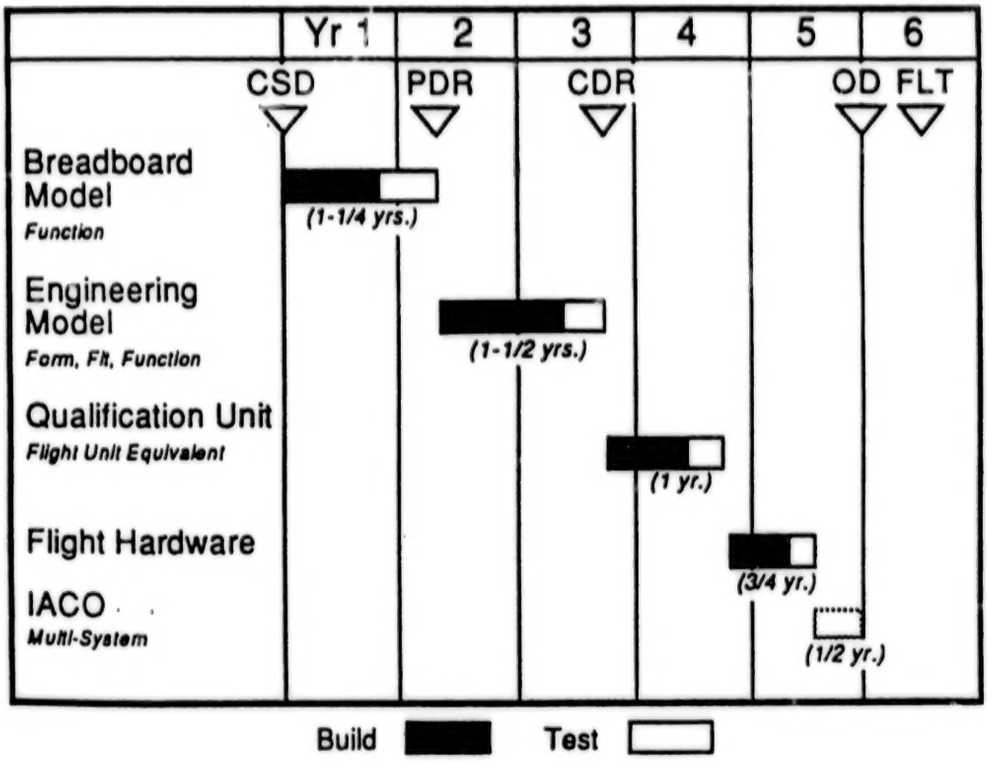

Figure 3. Single System Hardware Schedule Template
(About 5 1/2 Years From CSD to Flight)

Figure 3 shows a single system hardware schedule template which possesses the desired characteristics. Definitions of engineering models, qual units and flight hardware were provided earlier in this article. A breadboard model is built to support the preliminary design of a system. It is often a crude version of the actual flight component, but its primary purpose is one of proof-of-concept. IACO (integration, assembly and checkout) includes all labor and material required to assemble the multiple systems into flight packages and perform checkout of those flight packages. A similar single system software schedule template also exists, but is not displayed here.

Figure 4 shows an example of a completed one-pager. Starting at the top, several major project milestones and the multi-system hardware/integration/test program, or "backbone" have been identified. We have also used a hardware schedule template to select Subsystem 1 breadboard, engineering model, qual unit and flight hardware components. Subsequent discussions on selecting cost and metrics data will reference this example.

The next step in building a one-pager is selecting the appropriate cost baseline. The selected cost data must be concise and relatable to the schedule and metrics sections of the one-pager. Regardless of the source of the data, the first thing you ought to do is try to determine how the cost estimates were developed and identify the underlying assumptions. Make some common-sense

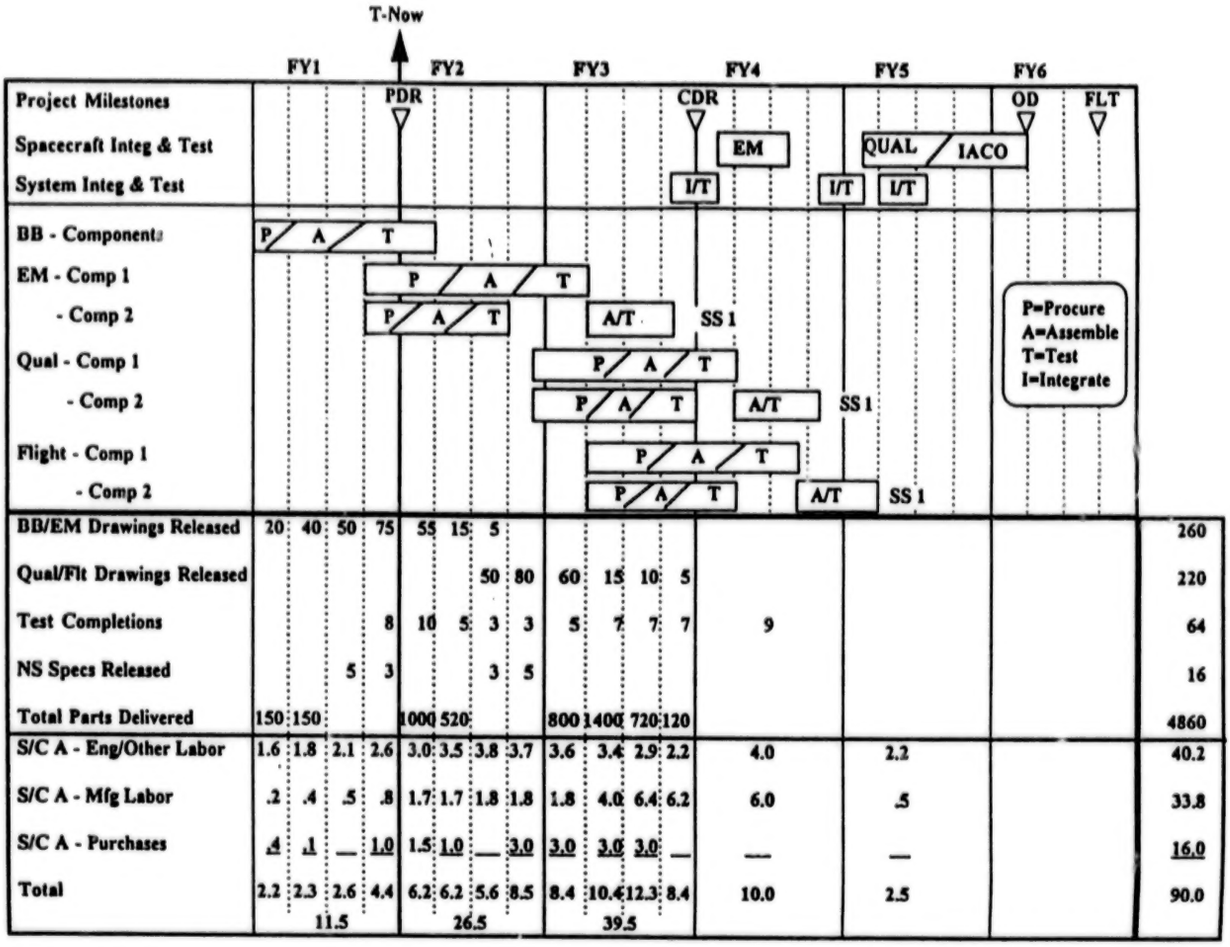
T-Now
FY1
FY2
FY3
FY4
FY5
FY6
Project Milestones
PDR
CDR
OD
FLT
Spacecraft Integ & Test
EM
QUAL
IACO
System Integ & Test
I/T
I/T
I/T
BB - Components
EM - Comp 1
- Comp 2
Qual - Comp 1
- Comp 2
Flight - Comp 1
- Comp 2
P A T
A/T
SS 1
P=Procure
A=Assemble
T=Test
I=Integrate
BB/EM Drawings Released 20 40 50 75 55 15 5 260
Qual/Flt Drawings Released 50 80 60 15 10 5 220
Test Completions 8 10 5 3 3 5 7 7 7 9 64
NS Specs Released 5 3 3 5 16
Total Parts Delivered 150 150 1000 520 800 1400 720 120 4860
S/C A - Eng/Other Labor 1.6 1.8 2.1 2.6 3.0 3.5 3.8 3.7 3.6 3.4 2.9 2.2 4.0 2.2 40.2
S/C A - Mfg Labor .2 .4 .5 .8 1.7 1.7 1.8 1.8 1.8 4.0 6.4 6.2 6.0 .5 33.8
S/C A - Purchases .4 .1 — 1.0 1.5 1.0 — 3.0 3.0 3.0 3.0 — — — 16.0
Total 2.2 2.3 2.6 4.4 6.2 6.2 5.6 8.5 8.4 10.4 12.3 8.4 10.0 2.5 90.0
11.5
26.5
39.5

Figure 4. Subsystem 1 One-Pager

observations to calibrate the level of risk flexibility inherent in the cost estimates. If cost data is available by functional break, combine related labor categories into a few summary cost elements appropriate to the one-pager you are constructing.

For example, if you have cost data with ten functional breaks and examination of the data indicates that three are related to engineering, four are related to manufacturing, and the remaining three don't appear to be related, you might want to combine this data into three summary cost elements: engineering, manufacturing and other. Then allocate the indirect costs (overhead, G&A, etc.) to the summary elements. Show a stream of actuals (if actuals exist) by quarter. A good rule of thumb is to collect quarterly data for at least one year prior to and two years after Tnow.

Figure 4 shows cost data at the appropriate level for that one-pager. After you lay out the summary costs, you should examine the time phasing of the data to test your expectations as to what that phasing ought to look like. For example, does engineering tend to peak around CDR and prior to manufacturing?

The final section of the one-pager to be completed is the metrics baseline. Metrics are quantifiable work indicators used to describe a plan or measure progress against a plan, and as such, supplement cost and schedule data. You should select metrics that are relatable to the development and manufacturing processes and to product deliveries. They should be phased quarterly for at least one year prior to and two years after T_{Now}, and should include total at completion. (Growth in metrics totals are almost certain indicators of problems.) As with both schedule and costs, make common sense observations about the data to identify any risk or flexibility inherent in the baseline plan. Some typical metrics used in one-pagers are as follows:

1. Drawing Releases—A measure of how the design is maturing. May be accumulated by end item and/or by fidelity.
2. Test Completions—A measure of how the design verification process is maturing. May be accumulated by end item and/or fidelity.
3. Parts Spec Releases—Another measure of how the design is maturing. May also be accumulated by end item and/or fidelity.
4. Parts Delivered—A measure of the magnitude of the work occurring within the parts procurement schedule.

If the item chosen for this one-pager uses non-standard parts, every effort should be made to ensure that they are included in the metrics you select. Unlike standard or off-the-shelf parts, non-standard parts are designed to meet and be tested against full-up requirements, and require their own unique development effort. They may comprise as little as 10 percent of the total parts, yet be as much as 90 percent of the total cost. Figure 4 shows the completed one-pager example with metrics included.

The next step in developing a one-pager is "scoring" the data in the baseline plan. Here we are concerned with the ability of the data to tell a story, not whether the story it tells makes sense. Ten items are to be scored, each worth a possible ten points using the following scale:

9-10 points: Little or no improvement possible
7-8 points: Improvement desirable, but not mandatory
5-6 points: Improvement mandatory
1-4 points: Little or no value in data provided

The first five items involve the schedule:

1. Backbone—The ability to tie products from completion through the next level of integration to flight.
2. Logic—The ability to follow the basic flow of effort within fidelity and from fidelity to fidelity, including contractors.
3. Correct Tabs—Assurance that the schedule tabs reflect the "drivers" for this one-pager. Generally intended to be product-oriented.
4. Near Term Density—The degree to which front end progress can be measured meaningfully on a quarterly basis.

5. Clarity—The general appeal of the schedule. The degree to which the level of detail is enough but not too much.

The next three items involve cost:

6. Completeness—The degree to which all numbers add horizontally and vertically.

7. Correct Tabs—Assurance that proper staffing categories are depicted, that labor and overhead dollars are visible, and that subcontractor and material items are identified–all at the appropriate level of detail.

8. Front End—Actuals by quarter are included and that at least near term quarterly data is laid out.

The final two items involve metrics:

9. Correct Tabs—Assurance that the proper indicators are identified. Can help clarify schedules and should relate in some fashion to the cost breakout.

10. Front End Completeness—Actuals and quarterly data are included. Degree to which all numbers add horizontally.

Examine the data found in Figure 4 and do your own scoring. You should find that the data used in the example scores very high.

The use of "scoring" criteria with which to evaluate the one-pager data has resulted in some unforeseen but very favorable consequences. There are times when, because the data you were provided is poor, you have to go back to the person who provided it and ask for something better. If, rather than relying on a subjective statement about the quality of the data, you are able to indicate that the data was examined and evaluated against a uniform set of standard criteria, your request for additional data may be received much more favorably.

The next step in preparing a one-pager is testing the baseline plan to determine if it makes sense from a top-down perspective. You are essentially addressing the following three questions:

1. Does the schedule make sense?

2. Is the cost phasing plan consistent with the schedule?

3. Is the metrics plan consistent with the schedule?

Does the schedule make sense? Assuming the schedule satisfied the scoring criteria, the major test here is whether the length of the activity bars makes sense with respect to one another.

Is the cost phasing plan consistent with the schedule? Engineering, manufacturing and vendor cost plans have unique cost profiles, or relationships, with the schedule. Prior to determining whether the cost phasing plan is consistent with the schedule, you should review your knowledge of these profiles and relationships. Next, examine the one-pager data and formulate a set of expectations based on your understanding of what should be occurring as indicated by the schedule

activities. Finally, test the credibility of the data versus your expectations. Figure 5 shows the schedule activities used in our one-pager example with an expected engineering cost profile plotted based on what the schedule indicates is occurring. The actual cost plan is then laid in at the bottom for comparison. In the Figure 5 example, the engineering cost plan passes the credibility test.

Is the metrics plan consistent with the schedule? Here you might examine the plan to see if:

1. Drawings for the appropriate fidelities are being released soon enough to properly support the assembly of those fidelities.

2. Test completions coincide with the testing activity bars in the schedule.

3. Non-standard parts spec releases for each fidelity lead the commencement of procurement cycle.

4. Parts deliveries occur during the latter half of the procurement cycle and support the assembly process.

An examination of Figure 4 shows the metrics data is reasonably consistent with the schedule.

The final step in completing a one-pager is measuring or assessing the risk inherent in the baseline plan. Although we have challenged and questioned the individual pieces of data used to construct the baseline plan, and have tested the plan to see if it made sense from a top-down perspective, we have

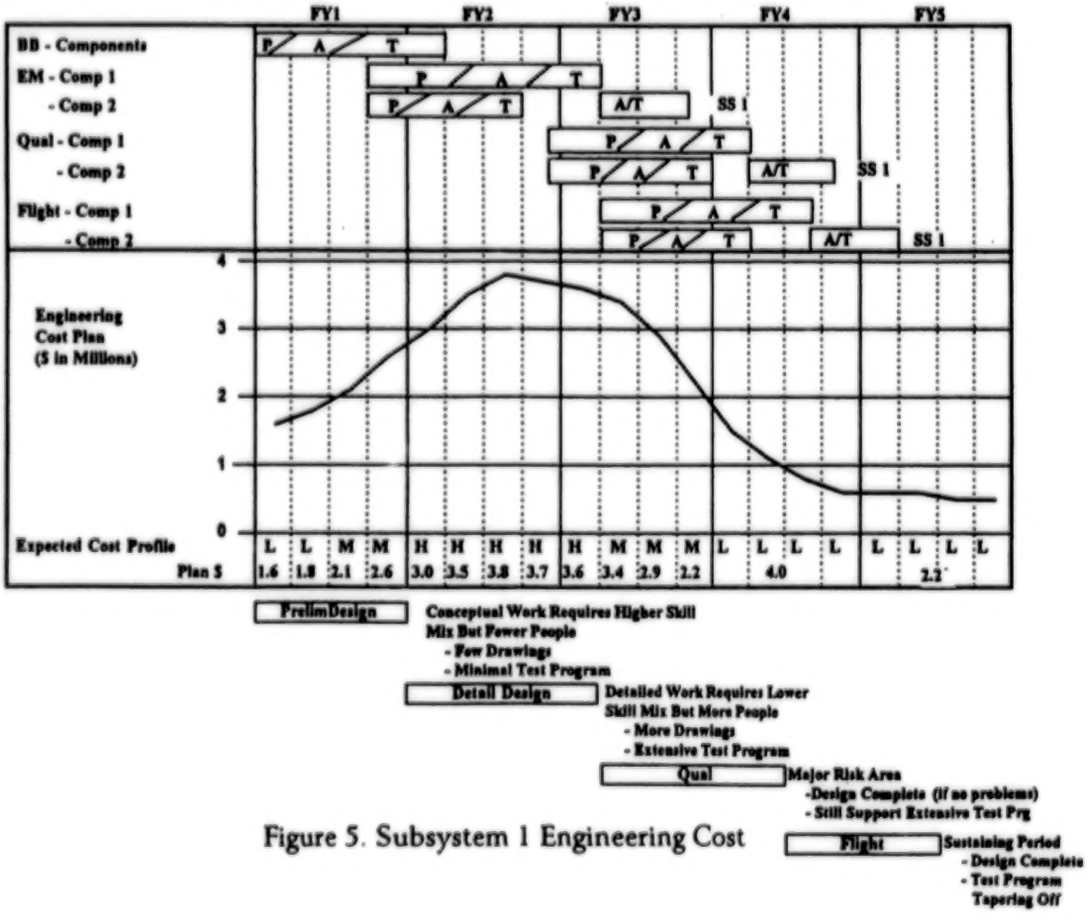

Figure 5. Subsystem 1 Engineering Cost

not yet determined the level of risk that is inherent in the plan. A plan may appear logical yet still possess a certain amount of risk. The decision as to how much risk may be tolerated in a program is often the product of political, budgetary and philosophical constraints. Risk must be assessed in terms of schedule, cost and metrics. We will refer to Figure 4 to demonstrate how risk in the baseline plan is evaluated. The following lists various aspects of schedule, cost and metrics, and ranks the attendant level of risk as low (L), medium (M) or high (H).

Schedule Risk

BACKBONE	RANK
Adequacy of test program	L
Time to complete integrated tests	L
Overlap/parallelism within integrated tests	M

While the integrated test program is generous (covers all fidelities), some overlap exists between qual/flight that merits noting.

Schedule Risk

SUBSYSTEM	RANK
Time to complete Breadboard	L
Time to complete EM	L
Time to complete Qual	L
Overlap/parallelism	M

While adequate time for completion of each fidelity appears available, once again, the overlap in the qual and flight programs merits noting. Early budget constraints may have forced this overlap, however, if future budget/schedule relief is granted, this area might be reevaluated.

Schedule Risk

OVERALL SCHEDULE	RANK
Overall concern level	M-L

Cost Risk

ENGINEERING WORK FORCE	RANK
Adequate EPs to support EM (CDR)	L
Adequate EPs to support Qual	M

Although the profile/shape of the curve appears as would be expected, the rapid tapering off after CDR assumes a successful EM program.

Cost Risk

MANUFACTURING WORK FORCE & PURCHASES	RANK
Plan consistent with schedule	L

OVERALL COST	RANK
Overall concern level	L-M

Metrics Risk

METRICS	RANK
EM drawing timeliness	L
Qual drawing timeliness	M
Parts deliveries timeliness	L
Test completions timeliness	M

Sixty-five percent of the EM drawings are complete at PDR and prior to assembly of component 1. However, the majority of the qual/flight drawings are completed during the EM test program. Ideally, you would prefer to have EM results available prior to starting the qual/flight drawings; however, this is most often not the case. Parts deliveries are consistent with the schedule. There is some concern with test completions because of the overlap between qual and flight.

Metrics Risk

OVERALL METRICS	RANK
Overall concern level	M-L

This completes the process of building a one-pager.

The one-pager was designed to fill the need of NASA program/project managers for a system that will facilitate timely, accurate top-down program/project assessments required to establish and/or assess the program's baseline plan, determine progress against the plan and assess planning alternatives. This article explains the process of building a one-pager to establish the baseline plan. While a discussion of how to use the one-pager to assess planning alternatives is beyond the scope of this article, it would be useful to show how simply but powerfully one-pagers can determine progress against a baseline plan.

Consider once again the example found in Figure 4. Suppose that T_{Now} is one year later, and the project manager wants a top-down assessment of the status of Subsystem 1. What do you do?

The first thing you might want to do is compare the actuals from the past year to the baseline plan as reflected in the Subsystem 1 one-pager. Figure 6 shows an easy way to make this comparison with a Plan vs. Actuals sheet; the actual assessment is quite simple. As shown in Figure 6, the overall schedule drifted approximately four months in a 12-month period, suggesting that only eight months worth of baseline schedule was accomplished. Thus, the schedule accomplishment ratio (SAR) would be approximately 61 percent.

$$SAR = \frac{6.2 + 6.2 + (2/3 * 5.6)}{26.5} = \frac{16.2}{26.5} = .61$$

Ninety-one percent of the costs in the baseline plan were expended. Thus, the spending ratio (SR) is 91 percent.

$$SR = \frac{24.2 \text{ (Actual Cost)}}{26.5 \text{ (Planned Cost)}} = .91$$

Therefore, the overall accomplishment ratio —a rough measure of how efficiently the project is working—is 67 percent.

$$AR = \frac{.61 \text{ (SAR)}}{.91 \text{ (SR)}} = .67$$

The number of drawings and non-standard parts specifications have grown by 16 percent and 25 percent, respectively, indicating a probable impact to both engineering labor and purchases cost.

	PLAN	CURRENT	
BB/EM Drawings	260	305	
Qual/Flt Drawings	220	250	
Total Drawings	480	555	+ 16%
NS Specifications	16	20	+ 25%

Only 60 of the 130 planned Qual/Flight drawings have been released. This, coupled with the previous observations, implies future engineering cost growth. Test completions appear consistent with overall schedule status.

The total number of parts required has increased by 13 percent, suggesting potential procurement cost growth.

	PLAN	CURRENT	
Parts	4,860	5,500	+ 13%

In summary, it appears that engineering overspent the plan by 15 percent due to design problems, and manufacturing labor and purchases costs lagged due to the slip in design products. These simple observations indicate that Subsystem 1 has become a significant problem requiring immediate attention.

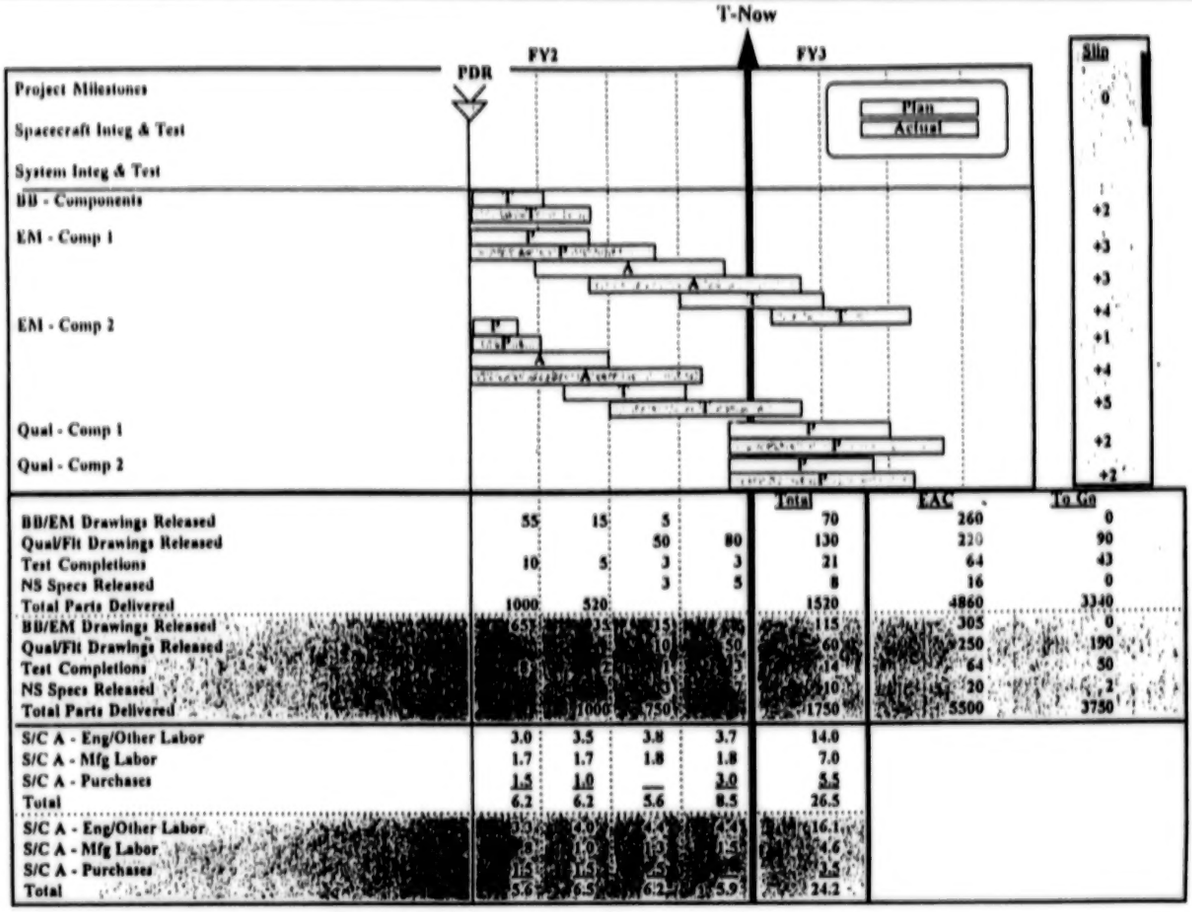

Figure 6. Subsystem 1 Plan vs. Actuals

It should be apparent that the one-pager system is more than just a tool. It is a process and a discipline that require both the preparers and the users to constantly probe, question, test, assess and ultimately, learn. If a program or project chooses to use the one-pager system to establish a baseline plan (and later to assess progress against that plan or assess planning alternatives), the users (managers, engineers and analysts) will soon discover that they have learned their program and the manner in which the cost, schedule and technical aspects fit together to an extent they might not have otherwise thought possible.

More importantly, they will be well on the way to developing a "feel" for the program, something that is crucially important but so often lacking. Finally, they will have at their disposal a powerful tool that permits them to manage their program more effectively.

Space Station Contract Negotiations: Principles and Process

by Ray Lugo

The Space Station Program has undergone more redesigns, rebaselinings and reconfigurations than any other major aerospace program. The path we are currently on for Space Station began in late 1993 with the Crystal City activities that resulted in the International Space Station Alpha and the selection of Boeing as the Prime contractor. The restructured program is constrained to a flat $2.1 billion per year funding profile and existing contracts that were novated to the Prime contractor. The original plan was to have a contract in place in early calendar year 1994. However, the activities associated with the redesign delayed any real progress in the contract negotiations until June 1994 and the selection of a dedicated negotiation team.

When the negotiation team was formed, the Estimate At Completion (EAC) for the Prime contract portion of the program was about $7.7 billion. This figure resulted from several cost reduction exercises initiated between the time the letter contract was signed and the middle of 1994. The Space Station Program, while still executable, would have been extremely difficult to manage within the cost estimates and the small reserves that would be available. The team's key objective was to negotiate a fair and reasonable cost estimate that would provide adequate reserves to resolve unknown problems in the future. No predetermined cost figures were used, but the team was challenged to negotiate a fair contract that would provide adequate reserves.

The hallmark of a successful negotiation would be a signed contract to accomplish the program within the budget and schedule constraints. This was the number one principle that the team followed. There was a basic understanding from the outset that we did not want to reduce the capability of the Space Station beyond the baseline we had established going into the negotiation. The team established a ground rule at the outset that "nothing would be thrown overboard" in order to achieve agreement . . . we would not reduce the technical content of the contract.

The key document for the contract was the Statement of Work (SOW), which was assumed to describe the content of the program accurately. Unfortunately, we found this was not so. When team leader Lee Evey discovered the SOW was under contractor control, we knew we had a problem. We expected Boeing to understand the content of the SOW, but we did not think they should be maintaining the most important technical document of the entire contract, determining configuration management.

The transfer of the SOW from the contractor to the negotiation team was a major undertaking. The conversion of the document from a proprietary format to one that the team could use and manipulate required an extensive effort. However, this task was small when compared to the task of rewriting the SOW and reaching agreement with the contractor on its content and interpretation.

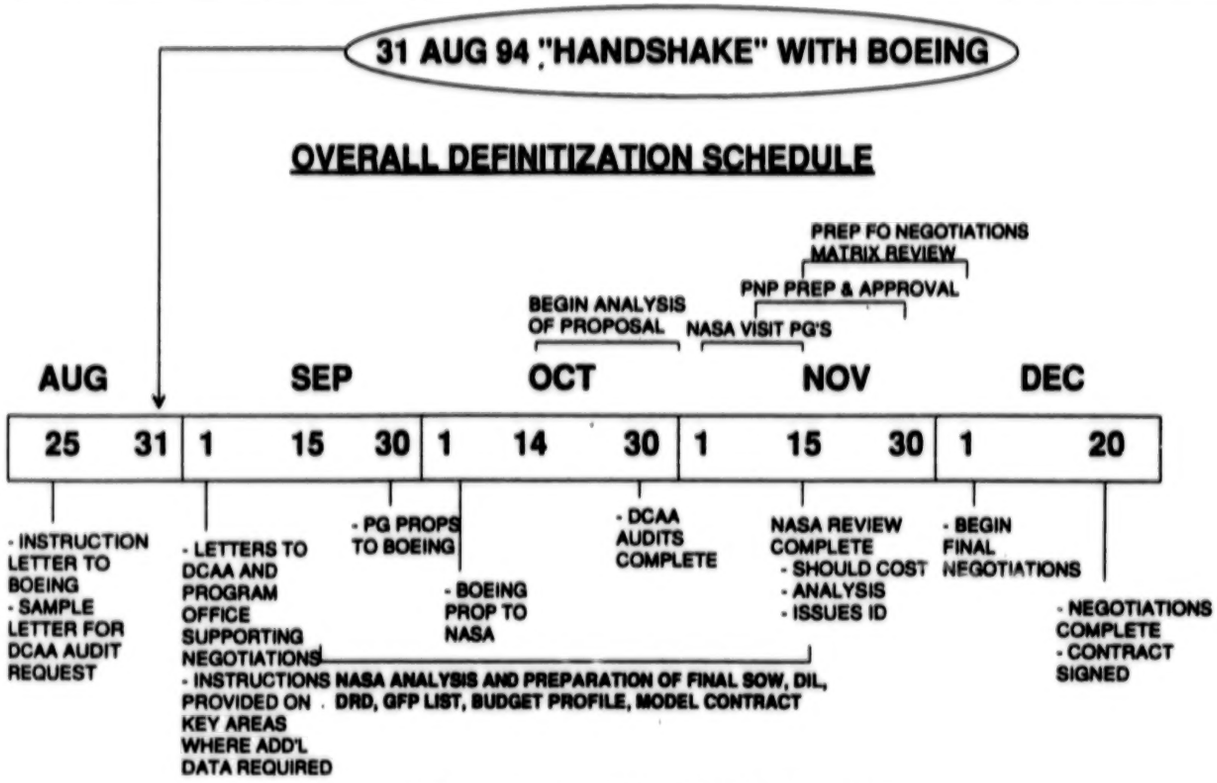
31 AUG 94 "HANDSHAKE" WITH BOEING
OVERALL DEFINITIZATION SCHEDULE
PREP FO NEGOTIATIONS MATRIX REVIEW
PNP PREP & APPROVAL
BEGIN ANALYSIS OF PROPOSAL
NASA VISIT PG'S
AUG
SEP
OCT
NOV
DEC
25 31 1 15 30 1 14 30 1 15 30 1 20
- INSTRUCTION LETTER TO BOEING - SAMPLE LETTER FOR DCAA AUDIT REQUEST
- LETTERS TO DCAA AND PROGRAM OFFICE SUPPORTING NEGOTIATIONS - INSTRUCTIONS PROVIDED ON KEY AREAS WHERE ADD'L DATA REQUIRED
- PG PROPS TO BOEING
- BOEING PROP TO NASA
- DCAA AUDITS COMPLETE
NASA ANALYSIS AND PREPARATION OF FINAL SOW, DIL, DRD, GFP LIST, BUDGET PROFILE, MODEL CONTRACT
NASA REVIEW COMPLETE - SHOULD COST - ANALYSIS - ISSUES ID
- BEGIN FINAL NEGOTIATIONS
- NEGOTIATIONS COMPLETE - CONTRACT SIGNED

Figure 1. Space Station "Handshake" Negotiations

Resolution of the SOW was a key element in the interim agreement (called the "handshake") with the Prime contractor. The "handshake" was a necessary interim step to show that the program was doable within the available resources. This helped assure the parties external to the negotiations that success was possible. The agreement on the SOW and its interpretation served as a risk mitigator to the contractor and enabled productive discussions regarding the cost of the program. However, these efforts were exceedingly strenuous and difficult.

The "handshake" was to be an enabling agreement to facilitate final definitization of the contract. In addition, the "handshake" served more importantly as an interim milestone toward the definitization that would demonstrate the "new" Space Station Program was making substantive progress toward the goal of building, launching and operating a Space Station. While the "handshake" met its external requirements, this interim agreement caused confusion about its role in the final definitization, despite efforts by both sides to clearly define the nature of this agreement. The Prime understood the agreement on price as a not-lower-than figure, while the NASA team used the "handshake" as a not-to-exceed figure. These divergent perceptions led to non-productive discussions at the start of the final definitization negotiations.

The nucleus of the NASA team, roughly 25 people, followed the negotiation from beginning to end, representing all the major subassemblies of the Space Station, the launch package managers, the supporting field

Centers and Headquarters. The diversity of this group provided the technical, business management and procurement expertise required to negotiate a contract of this size. The team was augmented during the fact-finding of the Tier II subcontracts and the Product Groups, but there were never more than about 70 people on the team at any given time.

While the team's diversity proved beneficial in resolving the technical issues, this was the first major procurement most of the cast had ever been involved in, and we required extensive training. Despite our inexperience, we were enthusiastic and confident that we could negotiate a fair and reasonable price to accomplish the task of designing, building and operating the Space Station.

Building 265 at Johnson Space Center was to house the team for the duration of the negotiations. Known as "The Bunker," Building 265 is best described as a hole in the ground with an air-conditioning system. It was believed that the negotiations would be enhanced by having both parties close to each other. During the first phase of the negotiations, NASA had approximately 70 percent of the space and Boeing had the remaining 30 percent. The arrangements were changed during the second phase of the negotiations with Boeing securing space elsewhere; both NASA and Boeing were aware that critical negotiation data needed more security.

The process employed to formalize the Space Station contract was a logical extension of the Product Team management approach used for the program. The NASA team represented all the elements of the Space Station Program, including the field Centers and Headquarters. Additionally, the team had a schedule, requirements and a budget to execute its task.

The formation of the team began with a briefing by the lead negotiator, Lee Evey, who declared that he did not have all the answers, and that we would have to do our homework to develop a fully documented pre-negotiation position. Lee also shared his experiences in negotiating other contracts and reviewed those lessons learned with the team. Lee's experience at negotiating contracts was extensive; for example, the negotiation of the $400 million Russian contract in support of Space Station. Lee emphasized that no two negotiations are alike and there is no "cookbook approach" for negotiating a contract. However, both contracts used tools in common to collect, organize and document the contract data for the purpose of developing a negotiation position. After careful selection of the negotiation team, the key common item was the diligent preparation of the team, the way NASA should.

The success of the negotiation would result primarily from our early preparation. The investment in training the team in the process, the time spent cleaning up the Statement of Work, the review of the proposal, the documentation of the government's position—all this prep work resulted in a final contract that is executable within the schedule, budget and technical constraints levied by the program.

From the outset, there were daily team meetings to discuss near- and long-term activities and priorities, and to communicate the latest information to each member on the team. The meetings, generally less than an hour in length, became a forum for the team members and an opportunity to hear first-hand how the NASA and contractor managers were reacting to the preparation and conduct of ongoing negotiations. We were guided through the process by the principle that we (the government) would take the "high ground" in the negotiation. This meant we would develop a fair position that could be logically tracked to the work to be done, plus a reasonable fee amount, taking into account relative risk, technical challenge and other factors. The bottom line was that the team represented all American taxpayers. We were also expected to take the high ground professionally and to treat the Prime with respect in all dealings. We knew that at the end of the negotiation, we would have to execute this endeavor as a team.

We also expected to negotiate a win-win agreement: both parties would leave the negotiation with the sense they had struck a fair and equitable deal that provided an opportunity for success. In face-to-face discussions, there were a few acrimonious sessions, but small outbursts were usually followed by the involved parties resolving the conflict and laughing about it later.

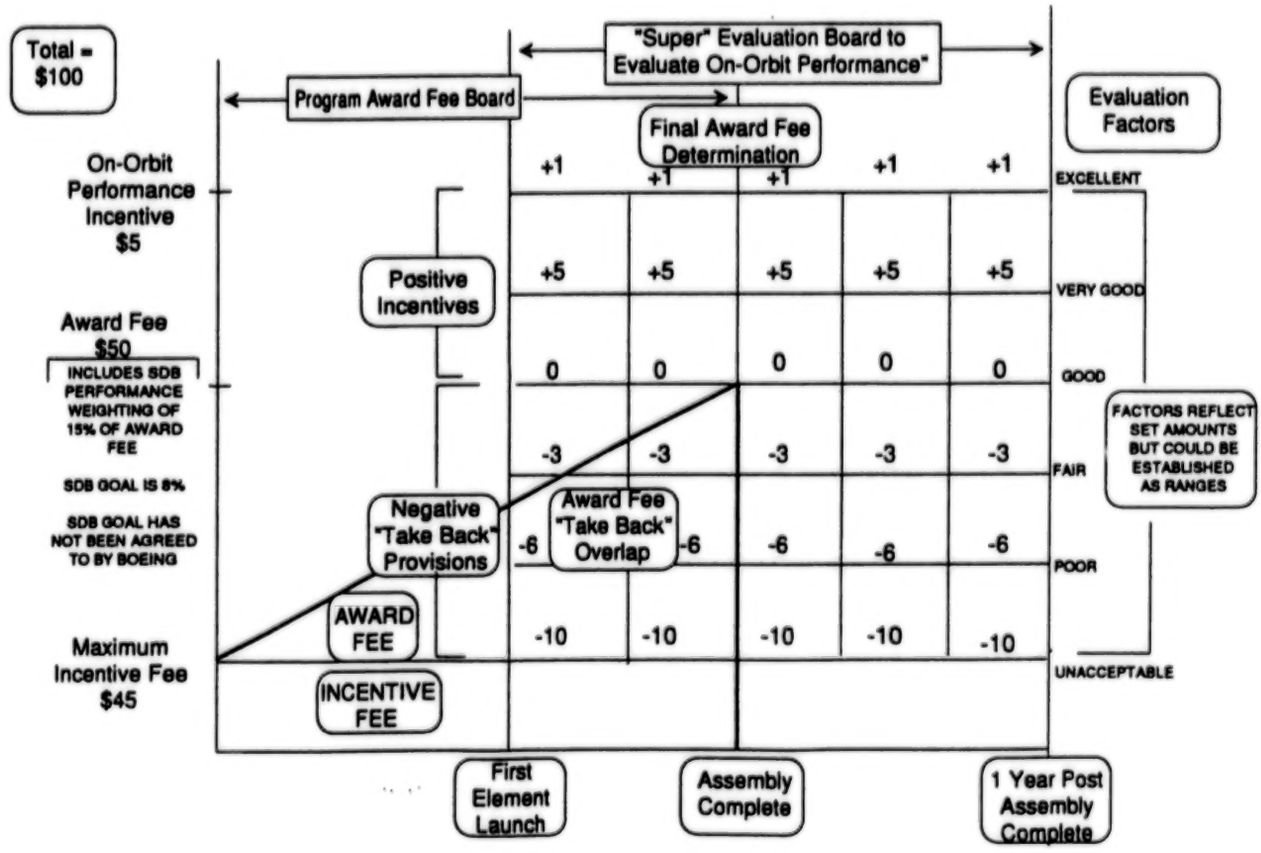

Figure 2. Award Fee Structure

NOTE: THIS CHART DOES NOT REFLECT THE FEE STRUCTURE OF THE DEFINITIZED CONTRACT
THE CONTRACT DOES NOT CONTAIN A POSITIVE ON-ORBIT PERFORMANCE INCENTIVE FEE FEATURE

In terms of preparation, this activity should set the standard for future NASA contract actions. Through diligent analysis and exacting preparation, the NASA team became experts on the content of the Prime's proposal. The NASA team's visits to major Tier II subcontractors and the Product Groups to review their activities resulted in our understanding of the status of the hardware/software development activities in the program before negotiations began. The Tier II subcontractors are the major component and subsystem providers to the Product Groups. The Product Groups are the Freedom Work Package contracts that were novated to the Prime during the Space Station program restructure.

The contract negotiation schedule was initially set to begin in July, with a "handshake" or interim contract by the end of August. Although these dates were later modified, the schedule was still quite aggressive considering that little progress had been made toward a negotiated agreement since the signing of the letter contract nearly two years earlier. Our first activity, to review and rewrite the Statement of Work, was a key element in the handshake agreement and one that established the framework for the contract. The clarification and revision of the SOW formed the basis for the proposals by the Prime and Product Groups. We found out later that the Prime did not have the Product Groups and Tier II subcontractors proposing against the revised SOW. This decision by the Prime was apparent during the Tier II reviews, when we discovered that the Tier IIs were building hardware to a different assembly sequence, to support a different vehicle configuration with a different set of performance requirements.

Besides the activity associated with the development of the Statement of Work, the team also took on the task of resolving problems with the Government Furnished Equipment (GFE), Government Furnished Property (GFP), Government Furnished Data (GFD) and the Deliverable Items List (DIL). The DIL documents the items of hardware, software and data required of the participants in the program to deliver the end-items. It also records the deliveries between the Tier IIs and the Product Groups, between the Product Groups and the Prime, between NASA and the Product Groups, and between the Product Groups and all the combinations of the above.

The agreement of the items, quantities and schedules for all the items on the DIL required the formation of a special team. The team reduced the discrepancies to less than 1 percent of the total items on the DIL before the negotiations concluded. The original documents had complicated the ability to resolve technical issues in the negotiations, and the contractor needed agreement on the items in the lists before committing to the delivery schedules. The review and agreement to the GFP/GFD/GFE lists were complete, except a few items, by the time the contract was signed.

The Tier II subcontractor review was a daunting but necessary task. To simplify the effort, it was decided that the criteria for review would be subcontracts with a value remaining of $50 million, which reduced the

number of contractors to be reviewed by two NASA review teams. The review was organized by the three Product Groups (PGs), the Major Tier I subcontractors within the Prime contract: McDonnell Douglas (PG-1)/ Rocketdyne (PG-2) and Boeing (PG-3). The teams were staffed with the system experts in each Product Group and a small "Core Team" that would perform horizontal integration. The process used to review the Tier II subcontractors was developed by the team to cover the critical elements associated with program and budget execution. The Core Team developed a standard list of questions mailed to each contractor approximately a week before the visit. Questions were standardized to determine if there was consistency in direction from the Prime and Product Groups or if there was a problem in interpreting program direction.

Before the reviews began, the team requested support from the Defense Contract Auditing Agency (DCAA) and the Defense Contracting Management Command (DCMC) in fact-finding and, subsequently, in contract negotiations. DCAA involvement in the process was invaluable in finalizing the contract. The Houston DCAA office assigned a liaison who resided on-site at JSC for the entire negotiation period and participated in almost every facet of the fact-finding and negotiation. Both DCAA and DCMC participated in the process with the negotiating team.

During the Tier II reviews it became apparent that the program was not heading in the direction the Product Groups had expected. Specifically, direction had not reached the contractors relating to the current configuration of the Station, the assembly sequence and the manifest. We determined that some of these communi-cation problems were the responsibility of the program, others rested with the Prime. This and other information gained during the fact-finding, while not necessarily a key element of the negotiation, would be critical to the successful execution of the program. Following the Tier II reviews a report was written by the team and presented to NASA management and eventually, to the Prime's management. The Prime seemed surprised at the state of affairs and used the report subsequently to negotiate with the Product Groups.

The review of the Tier II subcontractors was followed by the delivery of the proposal from the Prime. The proposal was divided into four sections: one section for the Prime and the remaining three sections for the Product Groups. The Prime had made no attempt to standardize or integrate the proposals. The content and format of each section were different, requiring a review to be done by volume (proposer) and the creation of a Core Team to review elements of the contract that crossed the Prime/Product Group line.

The team reviewed the areas of Operations, Utilization, Configuration Management, Information Systems, Procurement, Verification and Software, concentrating on consistency and the horizontal integration of the proposals. The Prime and Product Group teams performed the detailed technical assessment of the individual proposals. As part of the proposal review, fact-finding was done in each proposal. We determined

that a thorough review of each proposal would require five or six days of meetings, and that the meetings should be held at the contractor's site. The proposer would support each review, but the Core Team could not attend simultaneous meetings at four locations across the U.S. Therefore, schedules were staggered so that the Core Team could attend the first three days of reviews at each site.

The teams were also given one travel day between reviews (with the exception of Product Group 1 & 2 reviews, whose sites were not geographically distant from one another). The meetings were structured to cover all of the items the Core Team reviewed in the first three days, followed by more detailed technical briefings and follow-ups on the remaining days. After completing the reviews, the team returned to JSC, prepared a report for program management and developed a pre-negotiation position that was briefed to Headquarters and Space Station Program managers during the Thanksgiving break. The team also developed detailed cost models for each Product Group and the Prime. A set of standardized documents was employed for the Product Group and Prime assessments so data could be shared across the team.

The key element of the pre-negotiation position was the development of the negotiation range; that is, the range of prices in which the negotiation team would be free to strike a deal. This process was facilitated by the development of what we called the "matrix." The Matrix documented every element of the negotiation, to include the technical, cost, or schedule issues, the most aggressive cost position associated with that position (the best we could hope for) and the objective position (what we were sure we could get).

The Matrix document is broken into three parts: part one is issue identification, part two is issue discussion and part three is issue status. The Matrix is created on a word processor, maintained by the individual responsible for the topic area and continuously updated during the negotiations. The value of this document as a tool is hard to quantify, but one team member used to call it a $6 billion document. The Matrix allowed the team to focus on the issues, to detect where small concessions could be traded for large concessions and to provide a scorecard of the proceedings.

Formal negotiations were scheduled to begin in early December and conclude on the 15th; the contract signing would occur before the Christmas holidays. This schedule basically constrained the negotiations to about two weeks, an incredibly short period of time for a contract as complicated as this one. Typically, NASA negotiates a price that is higher than the proposed cost. This approach simply would not work in this case for a number of reasons. The most glaring reason was that the proposal delivered subsequent to the cost convergence activities of $7.7 billion did not fit with the program's funding constraints. The more important, but related, reason was that the contractor proposed early year funding requirements that made the program virtually impossible to execute.

These reasons motivated the team to explore creative ways to negotiate all of the Prime program content into the contract and to be hard-nosed negotiators. The NASA team thought the negotiations could be handled best by dividing the proposal into its components; that is, to negotiate the Product Group proposals and the Prime proposals separately. It was envisioned that these negotiations would be conducted concurrently and that the contract would be signed at a figure which represented the sum of the parts. While the negotiations were difficult, the team maintained professionalism throughout the process. We were confident that through preparation and honest negotiation, a fair and equitable deal could be struck. In the initial discussions, the Prime decided to fact-find NASA. In their view, NASA had already done all the fact-finding, depriving the Prime of the opportunity to fact-find the Product Groups and the Tier IIs. This role reversal was followed by the Prime's pronouncement that no agreements would be reached in the team sessions, which made the negotiation schedule impossible.

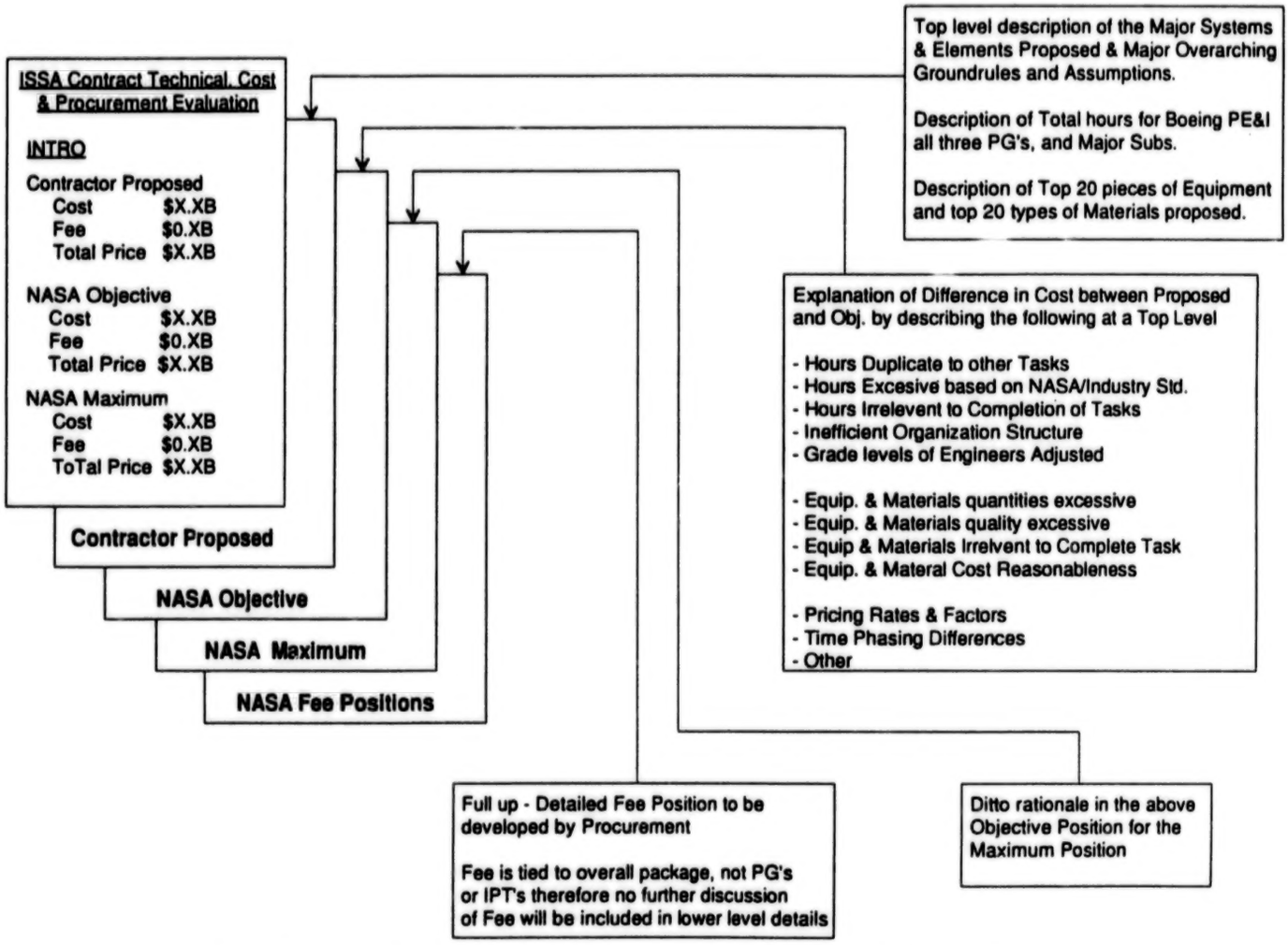
ISSA Contract Technical, Cost & Procurement Evaluation
INTRO
Contractor Proposed
Cost $X.XB
Fee $0.XB
Total Price $X.XB
NASA Objective
Cost $X.XB
Fee $0.XB
Total Price $X.XB
NASA Maximum
Cost $X.XB
Fee $0.XB
ToTal Price $X.XB
Contractor Proposed
NASA Objective
NASA Maximum
NASA Fee Positions
Top level description of the Major Systems & Elements Proposed & Major Overarching Groundrules and Assumptions.
Description of Total hours for Boeing PE&I all three PG's, and Major Subs.
Description of Top 20 pieces of Equipment and top 20 types of Materials proposed.
Explanation of Difference in Cost between Proposed and Obj. by describing the following at a Top Level
- Hours Duplicate to other Tasks
- Hours Excesive based on NASA/Industry Std.
- Hours Irrelevent to Completion of Tasks
- Inefficient Organization Structure
- Grade levels of Engineers Adjusted
- Equip. & Materials quantities excessive
- Equip. & Materials quality excessive
- Equip & Materials Irrelvent to Complete Task
- Equip. & Materal Cost Reasonableness
- Pricing Rates & Factors
- Time Phasing Differences
- Other
Full up - Detailed Fee Position to be developed by Procurement
Fee is tied to overall package, not PG's or IPT's therefore no further discussion of Fee will be included in lower level details
Ditto rationale in the above Objective Position for the Maximum Position

Figure 3. Format for Final Technical Evaluation – Overall Summary Level

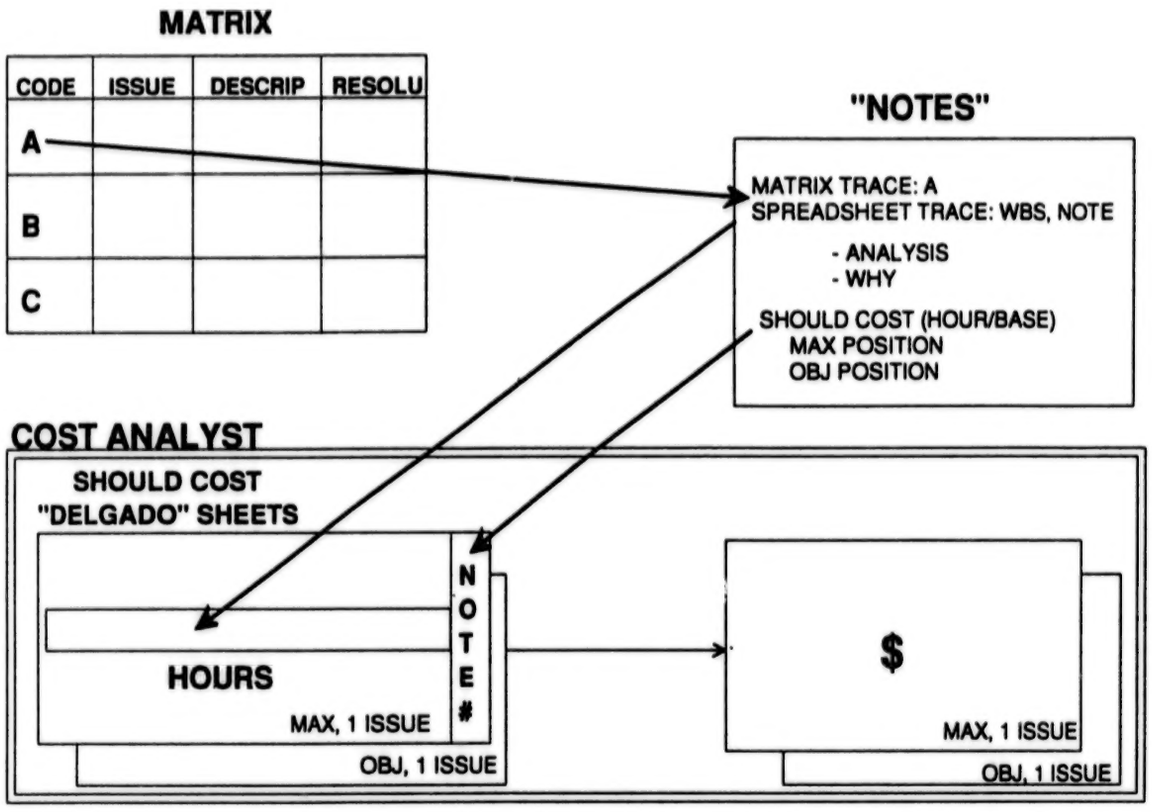

Figure 4. "Should Cost" Process

As the Prime's fact-finding proceeded through the Christmas holidays, a meeting was held between senior NASA management and Boeing corporate management. This high-level meeting was held between key Boeing executives, including the Chief Executive Officer, and NASA management, including the Administrator, the Associate Administrator of Space Flight and the Space Station Program Director. This meeting, central to the negotiations and to the NASA negotiation team, resulted in an affirmation by NASA management that the NASA team was empowered to negotiate the contract and that all negotiations would occur in The Bunker. Following this meeting, both teams were directed to redouble their efforts to negotiate the terms of the contract before the start of the New Year. When it became apparent that negotiations could not conclude that quickly, a Christmas holiday was declared. Negotiations were rescheduled to begin after the first of the year.

Once the negotiations began in earnest, there were numerous attempts to change the SOW so that the Prime and Product Groups could further reduce their risk and improve their opportunity for profit. In

general, the SOW was left unchanged, but several areas were rewritten or clarified to reduce possible ambiguities. Key issues between the parties were quickly identified, and strategies to resolve the issues were worked. Initially, all of the issues were technical execution issues. Cost issues did not surface until most of the technical issues were quantified and resolved. Probably the most contentious issue in the negotiations, except for the cost discussion, was the management of the assembly flights.

The issue of managing the launch and checkout of each element was critically important to the NASA team. It was essential to guarantee that each element would work on launch and in conjunction with the other elements already on orbit. The NASA position relied upon the management approach adopted for Space Station Alpha. During the transition at Crystal City, the Prime proposed managing the program by using the Integrated Product Team (IPT) approach. The IPT management philosophy divides a job up into its products and assigns a team to manage the development and delivery of each product. The Launch Package/Stage management teams were delegated with the overall responsibility of developing the flight hardware elements, performing the inte-gration and verification, conducting on-orbit checkout and acceptance, and operating the elements until the next stage arrives on-orbit.

This holistic approach to management, consistent with the IPT management approach, was unsettling to the contractor, since it pushed the budget, schedule and technical responsibility to a fairly low level in the contractor's organization. The Prime's main objection had to do with budget responsibility, as well as subcontract management and direction. The contractor could not accept a management approach that would have delegated the ability to commit to contract changes at this lower level. The Prime felt decisions that would affect the contract schedule, cost and/or technical direction had to be made by senior contractor personnel, and sub-contractor direction would have to be provided by subcontract managers.

This issue was finally resolved by mutual agreement. NASA recognized the significance of the risk the contractor was being asked to accept. The NASA management approach would have created a significant number of new subcontract managers, most of whom were experts in building hardware but who had little experience in managing subcontracts. The Prime understood the need to manage the "stages of assembly" and formed a new team, at a level high enough in the contractor's organization to minimize risk, yet responsive enough to manage the development of the hardware.

The contract was structured to implement new requirements that had been levied as a result of the Hubble Space Telescope. It was the first time that the new NASA award fee policy had been implemented in a major contract. Interjecting it into the contract—when negotiations to date had never had to address this issue—represented a major

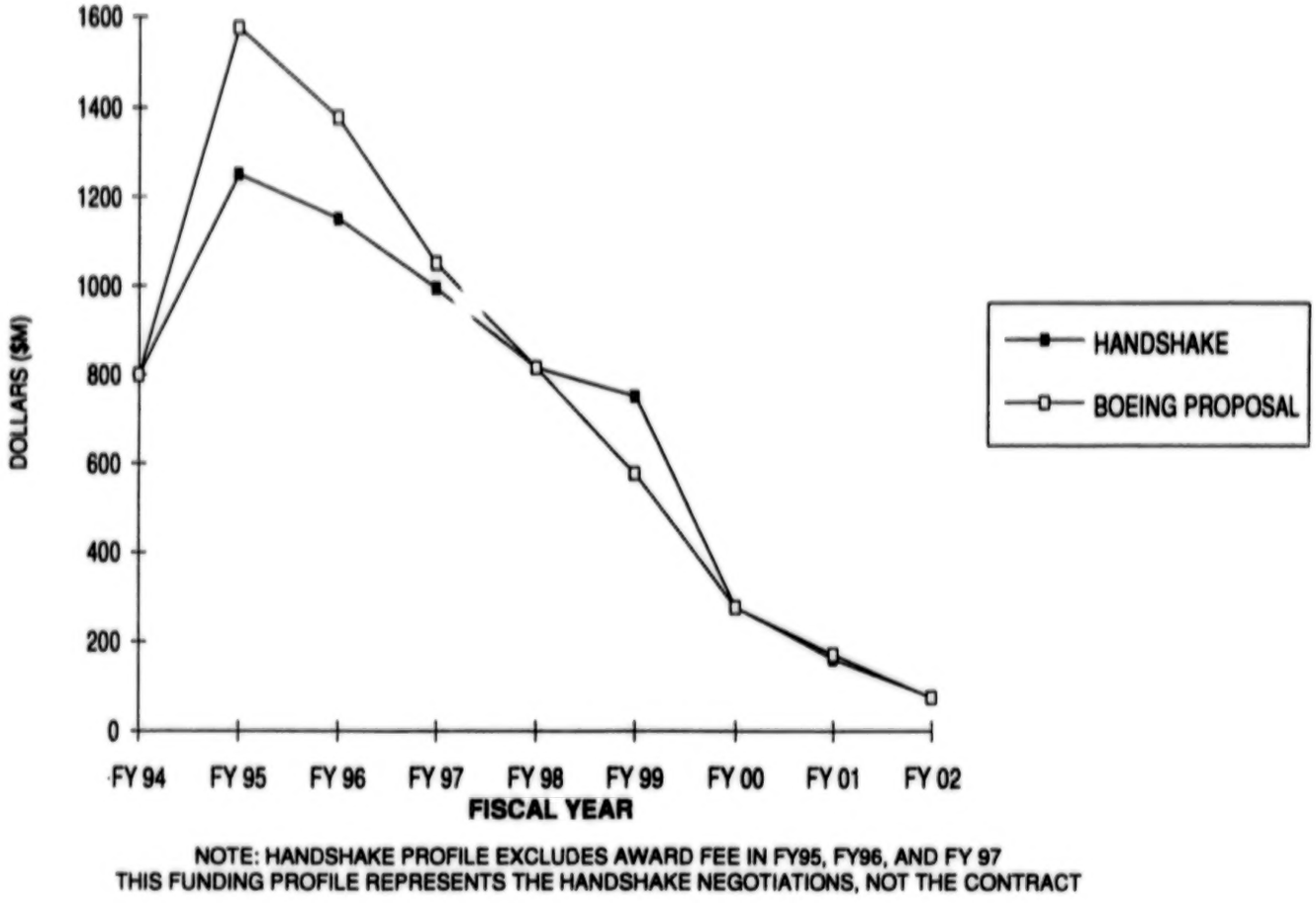

Figure 5. Final Negotiations, ISSA Letter Contract Definitization

change to traditional award fee operations and presented a significant challenge to both the contractor and government negotiators. The NASA award fee policy was originally written to be applied on more traditional NASA requirements where the mechanics of accomplishing the evaluation would be comparatively simple. For example, it assumes that award fee payments are accomplished on an interim basis or a relatively simple device, like a spacecraft, or as the spacecraft is built. Upon launch a determination is made of the spacecraft's performance and, if the performance exceeds targeted levels, an additional positive performance incentive is paid and all award fee payments are converted from interim payments into final payments. On the other hand, if performance falls below targeted performance levels, an award fee "take back" may occur where the final award fee payment determination is less than the total interim award fee payments already received by the contractor. The result is a refund by the contractor, back to the government, of the difference between the interim and final award fee payment amounts.

While such a procedure is complex, it was much more difficult in the environment contemplated for the International Space Station Alpha (ISSA). With ISSA there was not a single launch, but a series of 30 launches during which various capabilities and/or successive configurations would come on line, culminating in a fully operational ISSA as it moved toward final completion. It was further complicated by a seemingly infinite number of measures which could be employed to determine the success of ISSA. Through mutual hard work and effective problem solving by both parties, an approach was developed which allowed for periodic "final evaluations" at various key milestones in the in-space construction of ISSA. At these milestones, award fee "take back" analyses would be performed and awards based on the performance of the ISSA at the current stage of its development. These procedures, which serve to maintain high levels of contractor motivation across contract performance, also allow for the achievement of a series of final award fee payments at these mutual defined points of critical development.

The provision for fee take-back further complicated the negotiation, and was an element of risk that the contractor sought to mitigate. In the final contract, Boeing agreed to a plan that would allow for the award of fee through the execution of the contract, but would expose all the fee to the take-back provisions if the Station failed to perform on-orbit. In addition to the fee take-back feature in the contract, fee was used to encourage the contractor to reduce cost. The fee structure of the contract provides an opportunity for the contractor to earn an additional $ .25 of fee for every dollar of cost they reduce against the target price; on the other side of the equation, for every dollar overrun they would lose $ .25 of fee. This incentive feature could conceivably increase the effective fee while lowering the total costs by three times as much.

The agreement, reached late on a Saturday night, was followed by a victory celebration. Cigars were handed out to everyone as the negotiation teams moved outside "The Bunker." The negotiated price was more than $2 billion less than the EAC at the start of the negotiation, and the terms of the agreement clearly defined the content of the task, the schedule and the performance required. We had achieved our win-win goal.

The signing of the contract, the ceremonial activity associated with the conclusion of the negotiations, was conducted on Friday, January 13, 1995. The negotiations had taken almost 6½ months to complete. Just before the agreement was consummated, the NASA team determined that the Prime had already made money. A key contract provision was a sharing of cost risk; the contractor could benefit from contract underruns and would be penalized for contract overruns. During the closing days of the negotiations it was noted that one of the Tier II proposals had been updated, providing the Prime with a cost savings, and therefore a windfall profit just as the contract took effect.

The principles and processes developed during this intensive negotiation should constitute a new standard for all future NASA contracts.

Program Excellence: NASA's New Management Instruction

by Dr. C. Howard Robins, Jr.

In late 1992 the NASA Administrator established a Program Excellence Team (PET) to "strengthen and streamline the policies and processes governing management of our major system development projects." The Administrator promised the Space Council a single, comprehensive policy to combine NASA's program and acquisition management procedures. The new NASA Management Instruction 7120.4, dated November 8, 1993, is a product of our team findings and represents a major effort in genuine reform of program management at NASA.

Actually, the major factors leading to poor program and project management had been repeatedly identified for perhaps two decades, going back at least to NASA's Low Cost Systems efforts in the mid- to late-1970s. Over and over again, NASA had initiated new projects that exceeded available resources, both financial and institutional. There had been talk of major "buy-ins" on the part of contractors as well as NASA, and an unstable commitment from the Administration and Congress. Too many of these new starts suffered from inadequate definition, including poorly specified requirements and responsibilities that were either unclear or undefined, or both. As a result, program control to a defined baseline was virtually impossible. We knew all this, and yet there was poor follow-up on past studies, and where recommendations were put into policy, they were followed loosely or not at all.

Earlier in 1992, the new NASA Administrator Dan Goldin formed a Project Planning Team headed by Jack Lee, Director of the Marshall Space Flight Center, to identify chronic project planning problems and to offer solutions once and for all. The severity of these problems had been shown through a just-completed study of 29 recent projects that found schedule growth of 40 percent median (63 percent average), cost growth of 37 percent median (63 percent average), and a nominal definition/development life cycle time of 12 years. Clearly, NASA projects were troubled.

The 1992 Lee Study found eight major factors that typically drove NASA program cost and technical risk:

- Inadequate Phase B definition
- Unrealistic dependence on unproven technology
- Annual funding instability
- Complex organizational structures, including multiple or unclear interfaces
- Cost estimates that were often misused
- Scope additions due to "requirements creep"
- Schedule slips
- An acquisition strategy that did not promote cost containment.

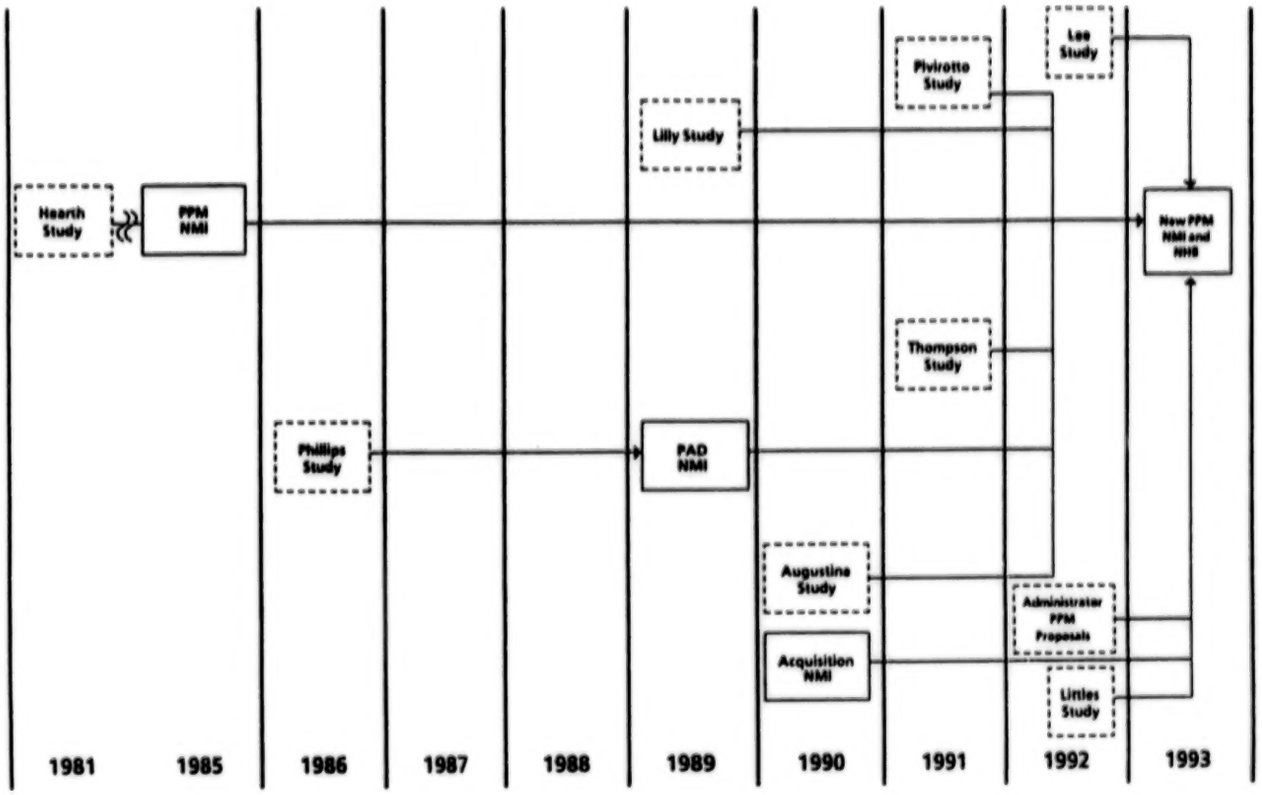

Figure 1. Program/Project Management History: 1981-1993

These factors were historically well known and undisputed, but the Lee team verified them in more than two dozen recent programs and projects. These chronic problems were still with us. Many of them had been duly noted in Don Hearth's classic 1981 study of project management, the Phillips NASA Management Study of 1986, the Lilly Program Control Study of 1989, the Augustine Report of 1990, Donna Pivirotto's Program/Project Management (PPM) Summer 1991 Study and J.R. Thompson's 1991 study on NASA Roles and Missions.

Armed with these insightful studies, our Program Excellence Team set out to consolidate and revise the three existing NMIs on program and project management. NMI 7120.3, dated February 6, 1985, covered just space flight program and project management. NMI 7121.5, dated March 14, 1989, instituted the Program Approval Document (PAD). NMI 7100.14b, dated February 27, 1990, covered major system acquisition.

Our first effort was to make sure the PET membership finally represented both program and critical support areas, such as procurement, comptroller and Safety and Mission Quality. Once formed, the team developed improvement proposals based upon the project planning team's recommendations, the results of the earlier stud-

ies and the Administrator's own program management policy proposals. We focused on internal improvements rather than external changes, and on major programs, we made a single but critically important assumption: that the Agency would operate within the framework of an integrated strategic plan with a set of priorities.

Our objectives were simple: Enhance delivery of performance on schedule and within budget; shorten the life cycle time.

The requirements we had to meet to achieve these objectives were considerably more complex. We knew we had to update PPM policy provisions to expand their applicability and scope beyond space flight and beyond the development phase. We knew we had to strengthen internal support for each NASA program, and that we had to plan and implement within available Agency resources (funding and institutional). We would have to streamline the life cycle process to assure adequate definition, technological readiness and validation of cost estimates with an expedited acquisition process and strengthened program control. Our approach would also have to clarify PPM responsibilities by establishing Agency-level PPM ownership and a clear chain of command.

We recommended the Deputy Administrator be assigned total Agency-level responsibility for all major system programs and projects. These are defined as any connected to an Agency mission entailing allocation of relatively large resources, or warranting special management attention. They include programs and projects with Development Cost Commitments (DCCs) of more than $200 million, those requiring external reporting on a regular basis, all multi-Center programs, and the first in a series of projects. The NMI excludes ground-based programs in research, technology development or space science, and exceptions granted by the Administrator, although the intent and underlying principles apply to all system programs and projects. (Recent changes in NMI 7120 may result in the inclusion of some technology development, such as the High Speed Research and the Advanced Subsonic Technology programs.)

The Program Excellence Team also recommended the formation of a Program Management Council (PMC), chaired by the Deputy Administrator, to assure Agency-level integration of planning, oversight and approval recommendation of major system development programs. The PMC would also provide Agency-level review and assessment of Agency technology and advanced development programs. Finally, the PMC would serve as a forum to address PPM policy and management issues as they arise.

To assure that the Agency program is in balance with available resources and to strengthen the support of the Agency senior management team for the total Agency program, approval of new programs and projects now comes from higher levels. Under NMI 7120.4, Phase A pre-implementation approval comes from the Program Associate Administrator, not the

Center Director, after needs are validated by users and mission needs are shown to be in accord with the NASA Strategic Plan. Phase B approval comes from the Administrator instead of the Program Associate Administrator. An additional approval cycle was added early in the program to force better definition efforts as well as to provide increased insight and, hopefully, commitment through all levels of the decision chain, including Congress. The Phase B definition effort was extended through PDR to support this process and avoid costly gaps in program implementation that were required by the existing life cycle.

The technical, schedule and cost commitments are embedded in a Program Commitment Agreement (PCA) process which replaces the Program Approval Document (PAD). In about six pages, the PCA is developed in Phase B studies and becomes a two-way commitment between the Program Associate Administrator and the NASA Administrator that is maintained throughout the life cycle. Similar agreements between Program Associate Administrator and Program Manager, as well as the latter and field Center project managers, form a clear commitment agreement chain, subject to annual or periodic renewal.

While project definition is being improved with additional planning requirements, acquisition management is improved in several major ways under NMI 7120.4. First of all, performance requirements, not design specifications, are specified as a nominal RFP approach, thus enhancing utilization of private sector capability and experience. Secondly, a "down-select" procedure during Phase B is specified as a nominal approach so as not to impede work flow unnecessarily. (Phase B Requests for Proposals will encompass Phase C/D in order to support competitive down-selection.) Thirdly, a contract budget plan and corresponding annual funding profile are included in the solicitation to promote realistic cost and technical proposals. Our PET team also recommended that a prime contractor be required for systems engineering and integration functions on large, complex programs involving multiple Centers.

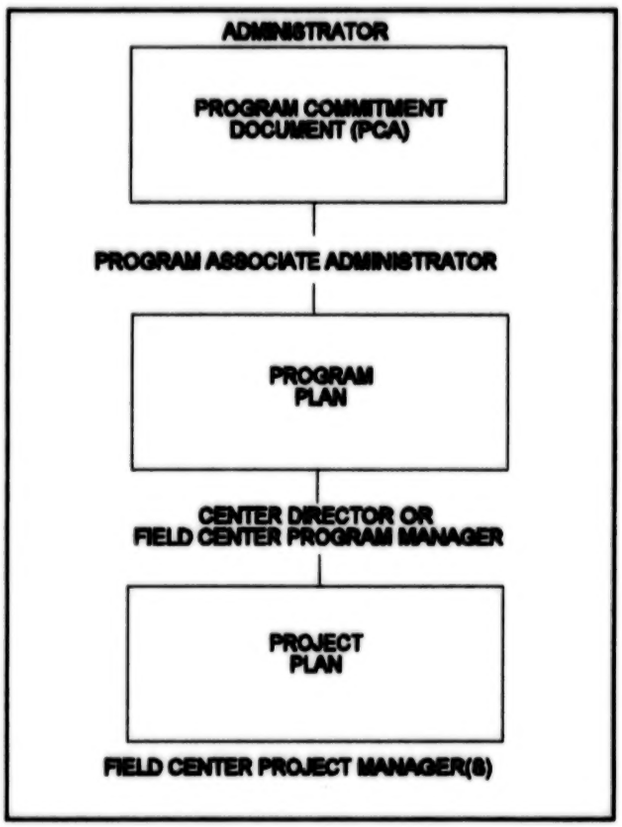

Figure 2. Commitment Agreement Chain

One of the most significant acquisition improvements comes from the addition of NASA "smart buyer" requirements. Phase A studies, which pin down the mission needs, will be conducted by civil service staff. Civil service staff will then parallel industry Phase B efforts, but on a smaller scale.

Also new are improvements in Program Control. Project baselines have to be developed early, and all projects with projected growth above 15 percent against cost commitments will be required to undergo Cancellation Review. Several requirements for external review have been added right through to Phase E, Operations, including the annual PCA validation, quarterly status reviews and mission reviews, now referred to as Independent Readiness Reviews (IRRs) and External Independent Readiness Reviews (EIRRs), coinciding generally with critical development decisions. Thus, the potential for surprises and cost growth is substantially reduced, and stronger program control, coupled with better definition and improved acquisition, should result in less time in the development phase. After all, time is money.

The NASA Administrator has accepted the recommendations of the PET team, approved the consolidated PPM NMI and promised Congress to implement program and project management reform. The PMC has been set up and PCAs approved for existing programs. The PET has conducted numerous briefings on NMI 7120.4, including those to senior management and others at each NASA Center and to several PPMI classes. After a year of operating under these new approaches, we have initiated selected updates to the process, based upon experience. We are now expanding our efforts to provide training on the new policies and processes, and to explain them to external stakeholders. Much remains to be done to implement and institutionalize the new NMI at Headquarters as well as the Centers. In addition, we need to ensure that OMB and Congress understand and support our new way of doing business.

Perhaps the most formidable challenge is cultural change. We have to learn to operate more at Agency level via integrated, prioritized strategic planning. We will need a more disciplined program implementation approach. The experience thus far indicates the change is taking place. We must make real commitments and renew them bilaterally on at least an annual basis.

We will have to improve our communications with OMB and Congress, who must be willing to provide substantial funding prior to Authority to Proceed. Following this formal approval, we must be disciplined in formally adjusting our commitments based upon their actions.

Contractors, too, need to adjust their strategies in response to NMI 7120.4. The cultural change here may be much more difficult to implement. A typical project may result in a significant contractor work force level prior to Authority to Proceed, creating a possible termination liability issue. In addition, a significant unplanned

gap between Phase B and Phase C/D may create a possible contractual or funding dispute. Buy-ins and unrealistically optimistic contracts will not survive under the new process. Change in this area is slow but already apparent. For example, all the contractors for the EOS contract were told recently to re-bid because of unrealistic cost estimates.

While the thrust of the effort to date has been directed at major programs, judicious application of NMI 7120.4 can help us achieve the objective of better, faster and cheaper on smaller projects as well. Cheaper and faster because of better definition, acquisition and program control, resulting in less development time. Better because it provides an integrated, disciplined approach to NASA program and project management based on a comprehensive response to past problems in project management.

In sum, implementation of the new policy should provide major improvements in program and project management. It assures new start compatibility with NASA's strategic planning and available resources. It enables OMB and Congress to claim "ownership" of each new start prior to go-ahead. It assures sufficient definition to make genuine, two-way commitments to NASA projects. It takes advantage of private sector experience and capability when performance specifications are part of the nominal Request for Proposal. And it establishes NASA as a "smart buyer" as well as a smart manager when Phase A studies are done inhouse, and Phase B definition is done in tandem with the contractor.

Adoption of the new PPM NMI can lead to substantial improvement, but alone it is not sufficient for real reform. Improvement also requires an aggressive, high visibility PPM continual improvement effort, focusing initially on further streamlining, and then on how to adapt the new policy and process to smaller programs and projects. We must retain the newly established ownership of the PPM function by the Administrator's office and commitment at all levels to be really effective.

Finally, we need to continue the Agency's strategic planning process to ensure our missions, programs and projects are part of a shared vision and common commitment. Only then can we say that we have truly learned from the past.

The AMSAT Microsat Satellite Program
An Example of Smaller, Cheaper, Faster, Better Communications Satellites

by Jan E. King and Robert J. Diersing

During the past five years, interest in low-cost space missions has increased at a rapid rate. In some cases, what is desired is a single, low-cost, physically small and yet highly-capable satellite for some specific mission. On the other hand, some applications require networks of multiple satellites. Engineers of these systems hope economies of scale will contribute to making multiple satellite systems cost-effective to build and operate.

Microelectronics and other technologies upon which space systems are built have most certainly advanced to the point where it is possible to build small, low-cost, and highly capable satellites. However, there is still relatively little experience at actually building small satellites, getting them into space, and operating them once they are on orbit. In spite of the recent interest in small, low-cost satellites, it may not be widely known that the amateur radio community has a long and productive record of small satellite development and operation.

The idea for the first amateur radio relay satellite is attributed to Don Stoner, who, in an article in the April 1959 amateur radio publication *CQ*, suggested that such a satellite be built (16). Fred Hicks, who had been associated with the first six Discoverer launches, was one of the many readers of Don's article (3). Fred initiated the first in a long series of events that resulted in the formation of the Project OSCAR Association in California and the eventual launch of the first amateur radio satellite, OSCAR I, on December 12, 1961. The acronym "OSCAR", which has since been attached to almost all amateur radio satellite designations on a world-wide basis, stands for ***Orbiting Satellite Carrying Amateur Radio***.

Project OSCAR was instrumental in organizing the construction and launch of the first four amateur radio satellites—OSCARs I, II, III, and IV. Since OSCARs I and II were in orbits that would decay quickly, they were equipped with only battery power and beacon transmitters. The transmission rate of the continuous wave (CW) beacons was a function of the spacecraft temperature. OSCAR III was the first amateur radio satellite to support communications relay as envisioned by Don Stoner, and about 1,000 amateurs in 22 countries used its relay capabilities (3). OSCAR IV, the last satellite built under the auspices of Project OSCAR, was launched December 21, 1965. Due to a failure of the top stage of the launcher, OSCAR IV never achieved the planned orbit, and side effects of its unplanned orbit caused its early demise. Although OSCAR IV operated for only a few weeks, some amateur radio contacts were made through it, including the first two-way satellite communication between the United States and the former Soviet Union.

While Project OSCAR was operating on the West Coast, a group of people with similar

interests was developing on the East Coast. In 1969, the Radio Amateur Satellite Corporation (known as AMSAT) was incorporated in Washington, D.C. As seen in Table 1, AMSAT has participated in many international amateur radio satellite projects, beginning with the Australis-OSCAR-5 project. Now, many countries have their own AMSAT organizations such as AMSAT-DL in Germany, AMSAT-UK in England, BRAMSAT in Brazil, and in Argentina, AMSAT-LU.

Because of the many AMSAT organizations now in existence, the U.S. AMSAT organization is frequently designated AMSAT-NA. All of these organizations operate independently but may cooperate on large satellite projects and other items of interest to the global amateur radio satellite community.

Beginning with OSCAR 6, radio amateurs started to enjoy the use of satellites with lifetimes measured in years as opposed to weeks or months. The operational lives of OSCARs 6, 7, 8, and 9, for example, ranged between four and eight years. All of these satellites were low-Earth orbiting (LEO) with altitudes of 800-1200 km. LEO amateur radio satellites have also been launched by groups not associated with any AMSAT organization such as the Radio Sputniks 1-8 and Iskra 2 and 3 satellites launched by organizations in the former Soviet Union.

The short-lifetime LEO satellites (OSCARS I-IV and 5) are sometimes designated the Phase I satellites, while the long-lifetime LEO satellites are called the Phase II satellites. The amateur radio community follows the usual convention of having one designation for a satellite before launch and another after it is successfully launched. Thus, OSCAR 13 was known as Phase 3-C before launch. The AMSAT designator may be added to the name, for example, AMSAT-OSCAR-13, or just AO-13 for short. Finally, some designator may replace the AMSAT keyword, such as the Japanese-built Fuji-OSCAR-20 (FO-20).

In order to provide wider coverage areas for longer time periods, design of the high-altitude Phase 3 series was initiated in the late 1970s. Phase 3 satellites provide 8 to 12 hours of communications for a large part of the northern hemisphere. After losing the first satellite of the Phase 3 series to a launch vehicle failure in 1980, AMSAT-OSCAR-10 was successfully launched and became operational in 1983. AMSAT-OSCAR-13, the follow-up to the AO-10 mission, was launched in 1988. AO-13 now provides most of the wide-area SSB and CW communications capability at certain times of the year despite the failure of its onboard computer memory. The successor to AO-13, Phase 3-D is already under construction and is scheduled for launch in 1996.

With the availability of the long-access time and wide coverage of satellites like AO-10 and AO-13, it may seem that the lower altitude orbits and shorter access times of the Phase II series would be obsolete. This certainly might be true were not for the incorporation of digital store-and-forward technology into many current satellites operating in low earth orbit. Satellites providing store-and-forward communication services using packet radio techniques are generically called *Pacsats*. Files stored in a

Table 1. Satellite Projects of the Radio Amateur Satellite Corporation in Cooperation with Other International AMSAT Organizations

NAME	LAUNCH DATE	LIFE/STATUS	NOTES
OSCAR 5	Jan. 23, 1970	52 days	Built by students at Melbourne University Australia. First satellite to have engineering and launch support from AMSAT-NA. No solar generator.
OSCAR 6	Oct. 15, 1972	4.5 yrs.	First long-lifetime satellite. In service for over four years. Battery failure.
OSCAR 7	Nov. 15, 1974	6.5 yrs.	First satellite to carry two linear transponders. Six-year lifetime. Battery failure.
OSCAR 8	Mar. 5, 1978	5.3 yrs.	Two linear transponders. Six-year lifetime. Battery failure.
PHASE 3-A	May 23, 1980	0.0 yrs.	Launch vehicle failure.
OSCAR 10	June 16, 1983	Lim. Oper.	First high-altitude orbit OSCAR. Two transponders. Operational when sun angle is favorable. Radiation-induced computer RAM failure.
OSCAR 13	June 15, 1988	In Oper.	High-altitude orbit OSCAR carrying four linear transponders. Will probably reenter sometime in 1996.
OSCAR 16	Jan. 22, 1990	In Oper.	First amateur radio "microsat". Digital store-and-forward file server.
OSCAR 17	Jan. 22, 1990	In Oper.	Educational microsat transmitting packet radio telemetry and digitized speech.
OSCAR 18	Jan. 22, 1990	In Oper.	Educational microsat built by Weber State University. Primary experiment is earth imaging system.
OSCAR 19	Jan. 22, 1990	In Oper.	Digital store-and-forward file server like OSCAR 16.
PHASE 3-D	Est. 1996		Now under construction by international AMSAT team.

Pacsat message system can be anything from plain ASCII text to digitized pictures and voice. The first satellite with a digital store-and-forward feature was UOSAT-OSCAR-11. UO-11's Digital Communications Experiment (DCE) was not open to the general amateur radio community, although it was used by the designated "gateway" stations. The first satellite with store-and-forward capability open to all amateurs was the Japanese Fuji-OSCAR-12 satellite launched in 1986. FO-12 was succeeded by FO-20 launched in 1990. In addition to providing digital store-and-forward service, FO-12 and FO-20 also have analog linear transponders for CW and SSB communications.

By far the most popular store-and-forward satellites are the Pacsats utilizing the Pacsat Broadcast Protocol. These Pacsats fall into two general categories—the *Microsats* based on technology developed by AMSAT-NA and the *UoSATs* based on technology developed by the University of Surrey. While both types are physically small spacecraft, the Microsat type satellites represent a truly innovative design in terms of size, capability and low cost. A typical Microsat is a cube measuring approximately 23 cm (9 in) on a side and weighing about 10 kg (22 lb) and will contain an onboard computer, enough RAM for the message storage, two or three transmitters, a multi-channel receiver, telemetry system, batteries and the battery charging and power conditioning system (10).

Amateur radio satellites have evolved to provide two primary types of communication services—analog transponders for real-time CW and SSB communications and digital store-and-forward for non-real-time communications. An evolutionary process has also occurred among groups sponsoring, designing, and building satellites providing amateur radio communications. For many satellite projects, the majority of the design, construction and operations tasks are handled by radio amateurs. More recently, however, there has been a trend toward other groups interested in satellite technology to design and build satellites that provide communications services to radio amateurs. Estimates of the out-of-pocket costs of a number of amateur radio satellites can be found in Table 2.

Table 2. Amateur Satellite Program Costs

OSCAR I	1961	$26
Australis-OSCAR-5	1970	$6000
AMSAT-OSCAR-6	1972	$15,000
AMSAT-OSCAR-7	1974	$38,000
AMSAT-OSCAR-8	1979	$50,000
AMSAT-Phase-3A	1980	$217,000
AMSAT-OSCAR-10	1983	$576,000
AMSAT-OSCAR-13	1988	$385,000
AMSAT-OSCAR-16	1990	$163,000
AMSAT-Phase-3D	1996	$4,500,000[1]

Source: Reference(8) except for last two projects.
Note (1): Estimated and includes launch costs. Total for all project participants. Not just AMSAT-NA share of costs.

The Microsat Project

More than five years have passed since the launch of four Microsat spacecraft developed by AMSAT-NA and other cooperating AMSAT groups. The four satellites, their primary missions, and owner/operators are: AMSAT-OSCAR-16 (AO-16 or Pacsat), store-and-forward file server system, funded and operated by AMSAT-NA; DOVE-OSCAR-17 (DO-17 or DOVE), space science education and the

promotion of international peace, funded by the Brazilian AMSAT organization BRAM-SAT; WEBER-OSCAR-18 (WO-18 or Webersat), space science education, funded and operated by Weber State University; and LUSAT-OSCAR-19 (LO-19 or LUsat), store-and-forward file server system, owned and operated by Argentina's amateur satellite organization, AMSAT-LU. While the Microsats were largely developed by AMSAT-NA, there was also participation by other organizations. An engineer from AMSAT-LU performed many of the spacecraft integration tasks and a Slovenian student studying in the U.S. did much of the design work for the transmitters. The Microsat program in general, and AO-16 in particular, show what can be accomplished by amateur radio satellite enthusiasts.

The Microsats were launched January 22, 1990, on Ariane mission V-35, the first mission to use the Ariane Structure for Auxiliary Payloads (ASAP). All of the Microsats were placed in nearly-circular sun-synchronous low earth orbits (800 km). The design and construction of AO-16 cost about $163,000. After more than five years in orbit, AO-16 and the other three Microsats remain in continuous operation. Figure 1 shows the assembled AO-16 Microsat and includes an exploded view of AO-16's internal modular structure. Operational aspects of the Microsat missions can now be described in detail followed by a discussion of techniques that contributed to their success while at the same time reducing costs.

Onboard Systems

There is little doubt that the AMSAT-NA Microsats have compiled an enviable performance record (4). This is true both in terms of the spacecraft themselves as well as the onboard computer software. There have been a few subsystem and component failures, but none of these failures caused the loss of a mission. Before discussion of the broadcast file server application of AO-16, a brief overall reliability review for all four AMSAT Microsats follows.

One measure of system reliability and availability can be obtained by monitoring the downlink of each of the four Microsats. The housekeeping task (PHT) periodically broadcasts a frame containing the current date and time as well as the total elapsed time the operating system kernel has been running. Note that the elapsed time applies to the operating system kernel and not to PHT or any applications such as the file server system.

Figure 2 contains a recent date/time/uptime frame from each satellite. The date/time in the first line of the pair comes from the clock in the ground station terminal node controller (TNC) whereas the date/time in the second line is from the clock in the spacecraft. The discrepancies between the two clocks are caused by infrequent checking and setting of the ground station TNC clocks.

From Figure 2 it can be seen that PACSAT (AO-16) and WEBER (WO-18) have uptimes of 642 days and 541 days respectively. In contrast to the long uptimes of PACSAT and WEBER, DOVE (DO-17) and LUSAT (LO-19) show relatively short uptimes of 43 days and 52 days. The 43-day uptime of DOVE corresponds to the time since a new

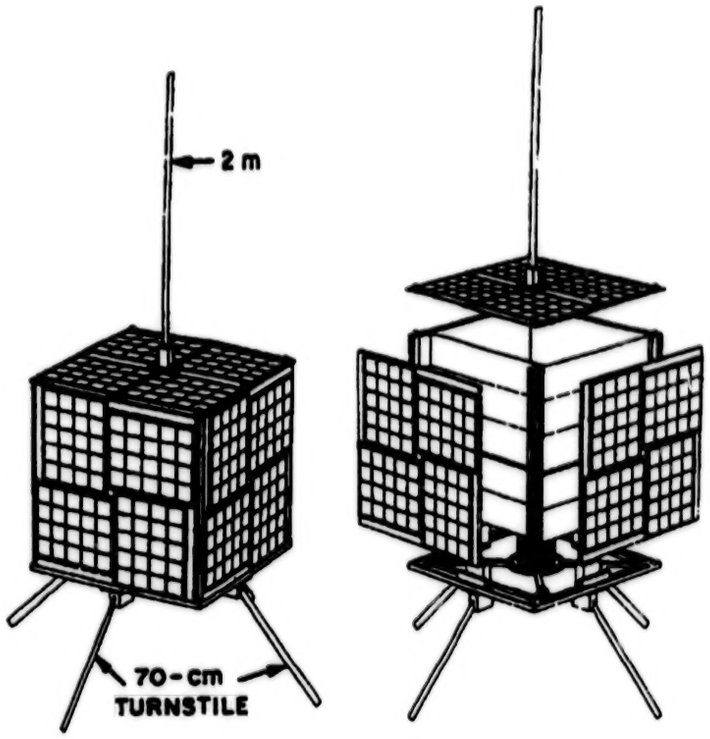

Figure 1. Assembled and Exploded Views of the AO-16 Microsat

operating system kernel was uploaded in preparation for speech synthesizer tests. LUSAT suffered an anomaly of unknown origin in mid-May 1994 that necessitated a reload of its operating system. However, prior to that incident it had accumulated nearly 1,000 days of uptime. The information in Figure 2 shows that all four satellites are currently in operation and that onboard computers and their software are quite reliable.

There have been no problems with the power generation, conditioning, and storage subsystems. Figure 3 shows a recent whole-orbit survey of available power for AO-16. For this particular survey, the whole orbit average power was 6.4 W while the average for the sunlit portion was 8.6 W. The plot does not drop to zero during eclipse because the power system design is such that during eclipse, the sensor is showing power required by all spacecraft systems except the downlink transmitter. In this case the power is being supplied by the spacecraft's battery.

Each of the Microsat flight computers uses an NEC V40 microprocessor. In addition, there is a Motorola 68HC11 in the DOVE speech module. None of these devices have experienced any type of failure, including single event latchups (SEL).

Each of the Microsats have 256 Kb of EDAC-protected static RAM for program storage and an 8 Mb non-EDAC-protected static RAM for data storage. There have been no permanent bit failures in the EDAC-protected RAMs. Bit errors in the non-EDAC-protected static RAMs are corrected by a software

```
PACSAT-1>TIME-1 [07/13/94 05:51:55] <UI>:
PHT: uptime is 642/00:44:54. Time is Wed Jul 13 05:46:59 1994

DOVE-1>TIME-1 [07/23/94 18:47:50] <UI>:
PHT: uptime is 043/04:46:40. Time is Sat Jul 23 18:47:18 1994

WEBER-1>TIME-1 [07/10/94 17:52:10] <UI>:
PHT: uptime is 541/22:13:40. Time is Sun Jul 10 17:52:16 1994

LUSAT-1>TIME-1 [07/10/94 17:22:29] <UI>:
PHT: uptime is 052/00:56:11. Time is Sun Jul 10 17:20:05 1994
```

Figure 2. Date/Time/Uptime Frames From Each of the Four Microsats

memory "wash" procedure. The memory wash cycle is done at a rate high enough to wash the entire 8 Mb in less time than it takes to pass through the South Atlantic Anomaly (SAA) twice.

Each of the modules within a Microsat communicates with the computer module via an interface designed around the Motorola MC14469 asynchronous addressable receiver transmitter (AART). One of a total of 16 of these communication paths has failed—the path from the DOVE speech module to the computer module. However, more than one trillion AART commands have been issued successfully by the flight computers and acted upon by the receiving modules—none have been lost or interpreted incorrectly.

AO-16, WO-18, and LO-19 have a pair of transmitters in the 70 cm band. In each pair, one of the transmitters utilizes a standard

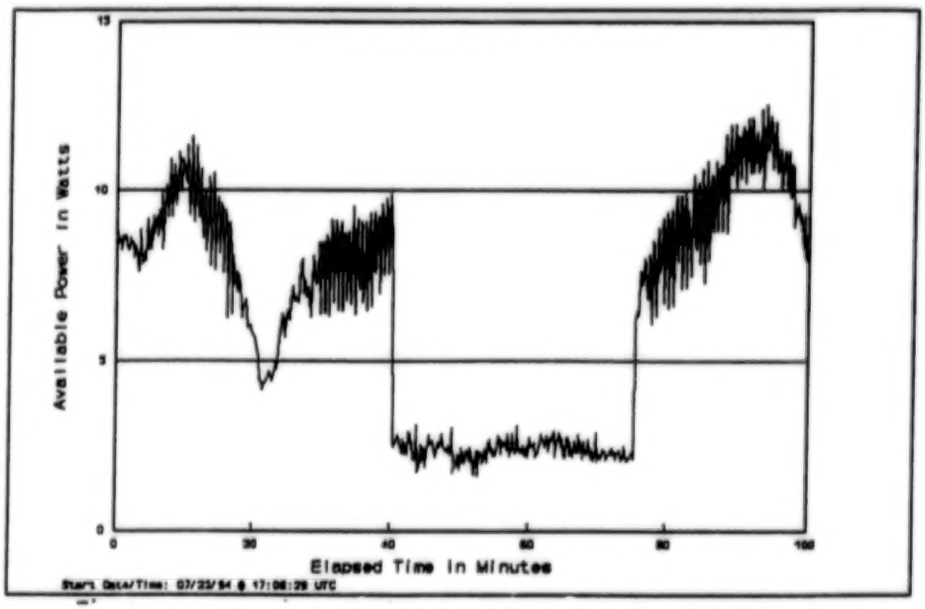

Figure 3. AO-16 Whole-orbit Survey of Available Power

PSK modulator and the other has a raised-cosine (RC) PSK modulator. LO-19 has an additional CW transmitter in the 70 cm band and AO-16 has a PSK third transmitter in the 13 cm (S) band. DO-17 has two AFSK FM transmitters in the 2 m band and a PSK transmitter in the 13 cm band. Problems have developed with the AO-16 and WO-18 70 cm and DO-17 13 cm PSK transmitter modulators. In all three cases, there has been a loss of carrier suppression, which is equivalent to a reduction in modulation index. The problem is much more serious on DO-17. In all cases, the cause is thought to be a small change in value of a piece part (capacitor).

None of the transmitter modulator problems had a permanent impact on the respective missions. For WO-18 and AO-16, operations were switched to the RC PSK transmitters. The near failure of the DO-17 13 cm transmitter modulator had a significant impact on software uploading capability. Other aspects of the mission have not been affected, however, because only the 2 m transmitter is used during normal operations.

Application Software

The primary mission of AO-16 and LO-19 is that of providing a store-and-forward communications facility in low earth orbit. During approximately the first 2 ½ years in orbit, the application software required to realize this mission evolved through several distinct stages of development.

For about the first year of operation, AO-16 and LO-19 provided what is called digipeater service. With this mode of operation, two stations within the satellite's footprint could connect to each other using the satellite as a relay. The amount of data transferred was, of course, limited by the time of co-visibility and the typing speed and proficiency of the ground station operators.

In late 1990, testing of the first version of the file server system began. This system allowed a suitably-equipped ground station to establish a connection with the satellite and upload and download files as well as download directories of files stored in the satellite's RAM disk. In addition to the connected mode of operation, the file server system also supported a broadcast mode of operation. With broadcast mode, a ground station could request the transmission of a specific file without establishing a dedicated connection.

The important difference in the two modes is that with connected mode, data transmitted on the downlink can only be used by the station establishing the connection, even though the downlink data is being heard by all stations in the satellite's footprint. On the other hand, downlink data resulting from a broadcast mode request can be utilized by any station in the footprint needing the information. Consequently, if several stations in the footprint need a particular file stored in the satellite, one broadcast request can potentially satisfy the requirements of all three stations.

Even though the first implementation of the broadcast mode provided the best method of operation in terms of potential downlink data reusability, some improvements were still required before use of the broadcast mode would supplant connected mode, especially for directory data downloading.

After nearly a year of uninterrupted operation, AO-16 suffered an onboard software crash on July 26, 1992. The crash was caused by the interaction between the spacecraft software and a user-written ground station program. Of course, if there were a single "factory supplied" program, these types of software failures would be much less likely. However, a unique practice of the Amateur Satellite Service is to allow users, who are so inclined, to write their own ground station software.

AO-16 was returned to operation quickly but the file server system was not placed in service again until October 16, 1992. The intervening time was used to run engineering tests and ready a new version of the file server software with enhanced broadcast mode capabilities. The most important of these new features were the transmission of directory information in broadcast mode and the capability of the satellite and ground station software to cooperate automatically to fill holes in broadcast files and directories. The software implementing the new broadcast mode facilities has been in continuous operation since it was started in October 1992. With the exception of file uploading, almost all access to the store-and-forward facilities is by the broadcast mode. Although the timeline has been slightly different, a similar progression of software installation has occurred on LO-19.

```
Download: Priority Auto Grab Never Fill Dir  Info. View dir. Quit! Help.
Message Holes  Size Offset Rcvd Auto: Fill, msg 5904, 1 holes.
                                Dir 5935 S:LO-19   T:LU8DYF F:G3RWL
     5925    4   N/A  2684      Dir 5937 S:REPORT LUS T:ALL  F:LU2BDTA
     5933    1  1974  1220 74% Dir 592c S:BL940717  T:     F:
                                Message 5904 heard.
                                Message 5904 downloaded.
                                Auto: Start, msg 58f7, 244 byte frames.
                                Message 58be heard.
                                Message 590b heard.
                                Message 5933 heard.
                                Message 58d2 heard.

PB: VY2DCS WA9MTO VE3FRH KM4EM N8WLJ VE3BDR WB4FIN\D W9ODI
OK KA9CFD
PHT: uptime is 646/11:13:12. Time is Sun Jul 17 16:15:17 1994
OK N5AHD
I P:0x1CFF o:0 l:902 f:960, d:1 st:5
PB: WA9MTO VE3FRH KM4EM N8WLJ VE3BDR WB4FIN\D W9ODI KA9CFD N5AHD VY2DCS
Open B D: WW8T  WA4UPD
PB: VE3FRH KM4EM N8WLJ VE3BDR WB4FIN\D W9ODI KA9CFD N5AHD VY2DCS
PB: KM4EM N8WLJ VE3BDR WB4FIN\D W9ODI KA9CFD N5AHD VY2DCS VE3FRH
Open B D: WW8T  WA4UPD
PB: N8WLJ VE3BDR WB4FIN\D W9ODI KA9CFD N5AHD VY2DCS VE3FRH KM4EM
DIR: Part (03)  AUTO: 58f7          s:0000 b:003590 d:001644 e:
```

Figure 4. Ground Station Computer Display
While Receiving Data From the Satellite Downlink

Details of typical ground station equipment configurations used to access AO-16 and descriptions of the software required to access the satellite's file system have been published (5). Figure 4 has been included as an example of a typical ground station computer display seen while utilizing AO-16 or LO-19. It should be noted that while Figure 4 shows the MS-DOS version of the user ground station software, MS-DOS Windows and Unix X-Windows versions of the software are now available. A version for IBM OS/2 is under development.

Activity log files are generated by the file server system on a daily basis. These activity logs can be downloaded and processed to extract usage statistics of interest. Figures 5 and 6 give a month-by-month account of AO-16 usage for 1993. In Figure 5, the left-hand bar of the pair is the transaction count and is read on the left-hand Y axis while the right-hand bar is the byte count and is read on the right-hand Y axis. Figure 5 clearly shows a decrease in activity in the summer months.

Figure 6 shows that almost all connected-mode activity results from file uploading. The total transmitted byte count for 1993 was about 650 Mbytes. At 1200 bps, about 4.75 Gbytes could be transmitted in a year. Consequently, 650 Mbytes represents about 15 percent downlink utilization excluding HDLC overhead, telemetry transmissions, and other types of downlink data. Of course, much of the time AO-16's footprint does not include any populated areas, so 100 percent utilization is not possible. On the other hand, effective utilization would be higher than 15 percent if one could estimate the data reuse factor. Remember that many stations can be using the broadcast mode data as a result of another station's request for a needed file or directory.

Table 3 shows the cash expenditures of AMSAT-NA for the construction and launch of AO-16. Readers should remember that this project was accomplished almost entirely with volunteer labor. The operating system software was donated due to the non-commercial nature of the project. The application software was designed, written, and donated by the radio amateur software team supporting the project.

Project Management

Having examined some of the design and operational details of the Microsats in general, and AO-16 in particular, along with the available cost data, we have shown reliable and low-cost satellites built by AMSAT-NA and similar cooperating organizations. What is required now is identification of specific techniques that may be applied in projects in other sectors. We will begin the discussion with the management structure and related personnel issues. However, other issues, such as parts selection, will be included because they are part of the overall project management philosophy and are important cost-reduction issues. One factor that will not be discussed to any great degree is the virtually non-existent labor costs arising from the volunteer, scientific, educational nature of AMSAT organizations. Since this aspect cannot be duplicated in any real-world commercial or governmental project, no benefit would accrue from giving

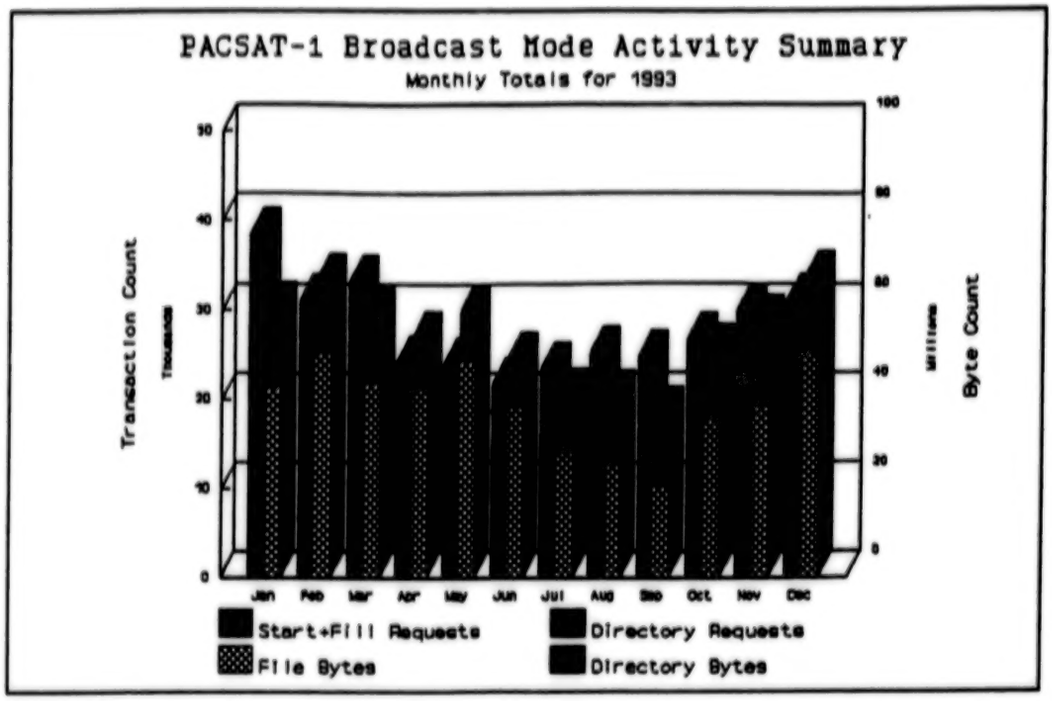

Figure 5. Month-by-month Broadcast Mode Activity Summary for AO-16

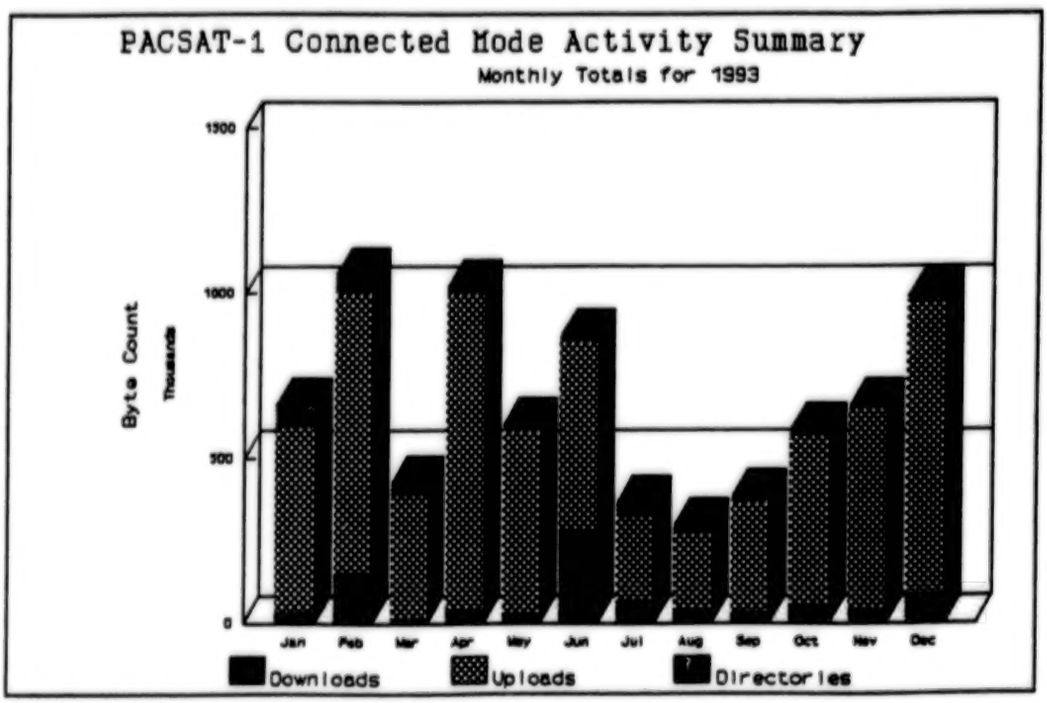

Figure 6. Month-by-month Connected Mode Activity Summary for AO-16

Table 3. Itemized List of AO-16 Project Costs
(FY1989 $)

Components	$ 14,883.01
Subcontracts	16,995.93
Non-recurring engineering	21,422.00
Salaries	3,070.76
Equipment rental	123.73
Facilities rental	3,206.71
Share of launch costs	20,352.20
License fees	1,023.85
Liability insurance	1,253.87
Other insurance	262.50
Documentation	2,675.00
Telephone	13,822.05
Electronic mail	13,531.17
Travel	38,028.47
Printing	1,530.42
Postage	4,847.15
Supplies	1,366.57
Photography	658.12
Advertising	300.00
Accounting	917.22
Miscellaneous	2,685.68
TOTAL	$162,956.41

it further attention. This is not to imply that there has never been any paid personnel working on an AMSAT project. Salaried personnel have been used at critical phases during several of the projects, but such expenses have been kept to a minimum.

It should be clear what motivated development of the AMSAT philosophy in the first place. The true motivation for reducing costs occurs when there is ***no money*** or the amount of money is very small compared to the amount that would be spent if a similar project was undertaken in the commercial sector. What develops from the lack of adequate funding is a philosophy that allows new, cost-effective techniques to be tried. The AMSAT philosophy continues to develop as more information is collected while applying and refining techniques. The refinement process includes the application of new technologies as soon as they are practical.

Management Structure

AMSAT has found it beneficial to utilize multi-disciplinary managers, engineers, and technicians in its satellite projects. Figure 7 shows the personnel mixture in a typical non-amateur satellite project (9). Some of the various technology areas are shown in the columns while the skill levels are shown in

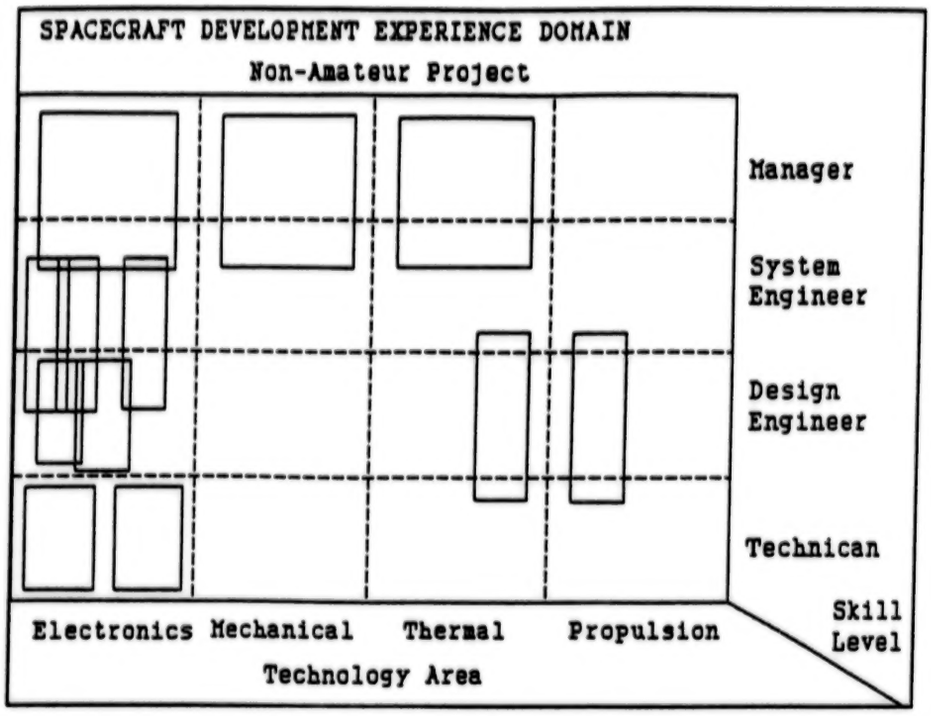

Figure 7. Personnel Mixture for a Non-amateur Satellite Project

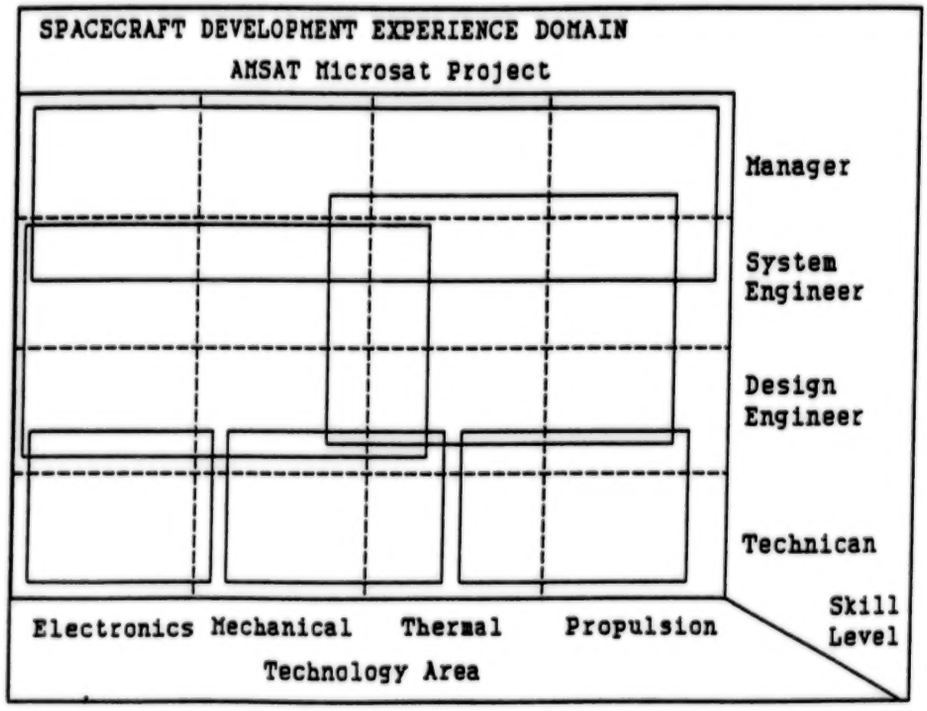

Figure 8. Personnel Mixture for a Cost-effective Satellite Project

the rows. The progression is from managers and senior engineers at the top, through the junior engineers, to the technicians. Figure 7 illustrates a personnel mix where the level of specialization is high. Moreover, the fact that personnel do not cross technology areas implies that some (probably expensive) interface control procedure must exist.

Figure 8 represents a more ideal personnel structure that is similar to that used on the Microsat project. Here, there is one broadly experienced project manager with a couple of senior engineers covering multiple skill levels and technology domains. In a similar vein, technicians also cross technology areas and have some design engineering skills. Two attributes of AMSAT personnel must be carefully considered—motivation and skill level. It has already been stated that most personnel working on AMSAT projects do not receive any monetary compensation. Why, then, are they motivated to expend their valuable time working on a satellite project?

The answer, of course, lies in the fact that they have their own particular motivations. For the project manager, it may be that a design concept could not come to fruition in any other way. For other participants there is a whole spectrum of possibilities. Perhaps the software designer wishes to take on the challenge of writing a reliable and fault-tolerant satellite-based application. Maybe, the technician has strong philosophical attachment to one or more system design concepts or to the application of the finished product. And, it could be that the person derives satisfaction in working on something that will go into space. The point is that managers of non-amateur projects must choose a staff that is similarly motivated or create the motivation within the staff—probably some of both. When the staff is not positively motivated, the reliability and performance of the systems built will suffer. Acceptable salary levels are not always sufficient motivation to do quality work. The motivation to do quality work comes about partially by training and partially by example. It is management that must first give the example and then choose personnel who can propagate the example.

In amateur radio satellite projects, skill level of the participants encompasses more than expertise in some required specialty. It means diversity of skill and the appropriate mixture of theory and practice. Many amateur radio operators, and not just those who happen to be associated with satellite projects, began the pursuit of their hobby in grade school. So, by the time they reach the prime of their careers at age 40 to 50, they have 30 to 40 years of experience behind them. From these years of experience come the abilities to cross technology area boundaries, to make cost versus performance tradeoffs, to try innovative designs, to minimize failures, and to do what cannot be done very easily on a shoestring budget.

Parts Selection

AMSAT has much experience to offer with respect to parts selection for spacecraft projects. The most important aspect of that experience is the characterization of the in-orbit reliability of the lower MIL-HDBK-217F classes and unclassified parts.

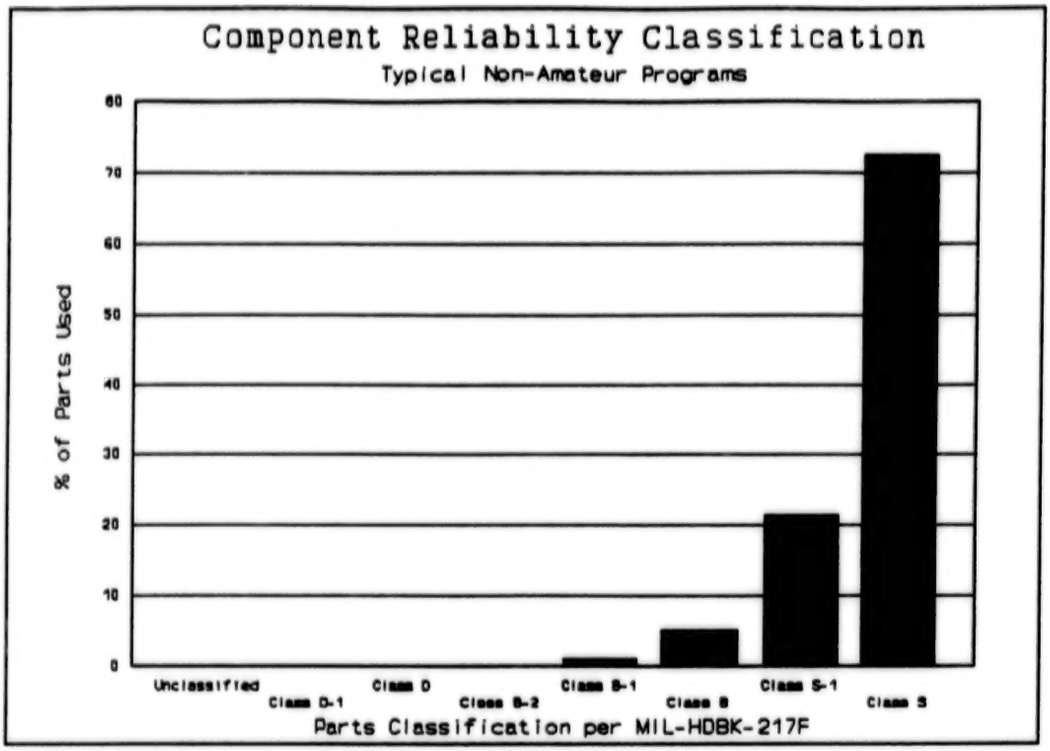

Figure 9. Typical Component Classification Mixture for a Non-amateur Satellite Project

Figure 9 shows a typical parts classification mixture for non-amateur programs. Figure 10 gives the parts mixture for the AMSAT-NA Microsat program. The in-orbit problems and subsystem failures encountered in the Microsat program have already been given, but recall that none of the failures has resulted in the loss of a mission.

The following observations have been made by AMSAT project management (9) with respect to parts mixtures:

- The best parts available rarely fail.
- Confidence exists in proven techniques.
- Not only are parts reliable, they have margin over the specified values.

But,

- The highest price is always paid.
- The schedule will always be long.
- Using good parts can mask a poor design.
- There is no knowledge about how lower-class and unclassified parts work in space.

Having employed parts mixtures of the type shown in Figure 10, AMSAT has found that:

- Good circuit design is more important than device technology.
- A practical approach to reliability must be developed based on cost.

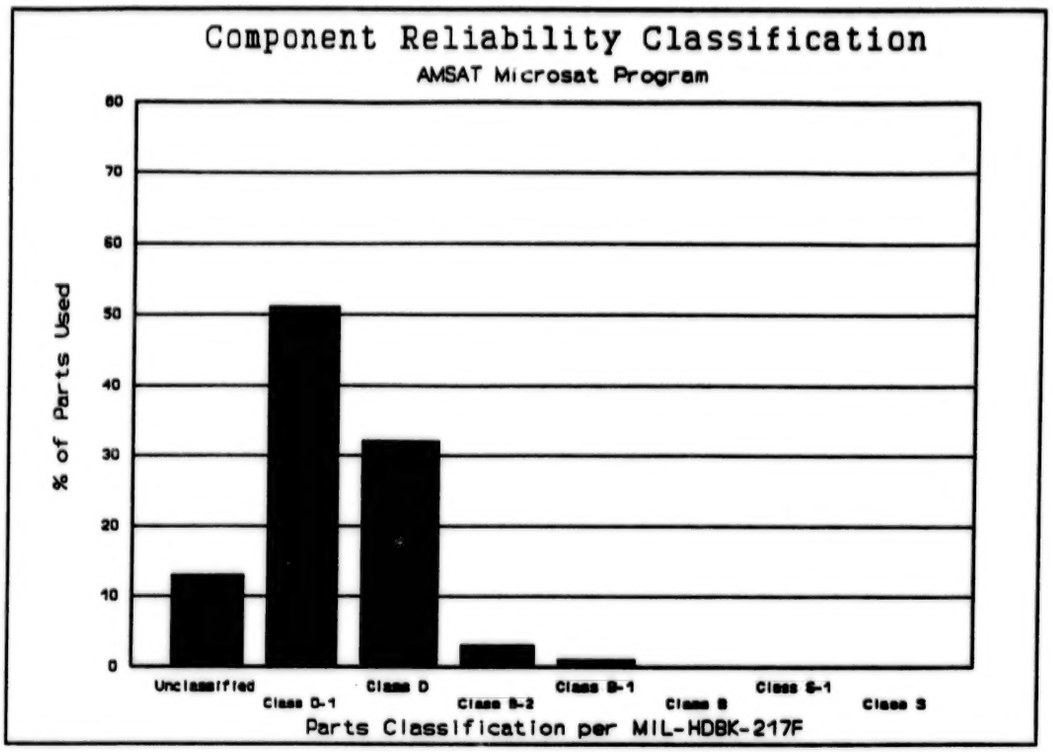

Figure 10. Component Classification Mixture for AO-16 and the Microsat Program

- Because experience is gained over a large portion of the reliability classification line a database is established that can be applied to future projects.

On the other hand, there are risks associated with the first in-flight use of components and the primary payload customer may be concerned with the parts choices made by the secondary payload customers. However, the risks can be largely mitigated by appropriate testing prior to launch.

Radiation Issues

The issue of parts reliability encompasses the question of radiation tolerance of components and systems and AMSAT's experience in this regard again differs with widely-held opinion. Specifically, AMSAT has found that radiation hardness/tolerance requirements are actually two to three times less than industry practice. This is not to say that AMSAT satellites have not experienced any radiation-induced failures. Indeed, AO-10's flight computer is inoperative due to the radiation-induced failure of its RAM. On the other hand, though, AO-13 has now been in a Molynia orbit for nearly seven years with no radiation-induced failures.

AMSAT's experience with radiation issues (9) has led to the following philosophy:

- Use rad-hard parts if they are available and affordable.

- Use specially-processed standard parts if they are available and affordable.

- Try to use parts with gate geometries no smaller than 1.0 micron.

- Use parts that are known to exhibit acceptable performance by virtue of the reliability experience data base.

- Protect against memory problems by using EDAC and software memory wash.

- Protect against processor setup table corruption by using hardware watchdog and/or fire code methods.

- Don't use more microprocessors than necessary.

- Ignore the issue of single event latchups.

The AMSAT Microsats, which include AO-16 described earlier, provide clear evidence that the AMSAT philosophy with respect to radiation issues is valid for low-cost LEO spacecraft. Each Microsat flight computer contains 453 integrated circuits and none are radiation-hardened parts. Only the boot ROM is Mil-Std-883. The net result is a total of over 1,800 ICs spread among four flight computers with a total of over 20 orbit-years (five years per satellite) of operation and no identifiable radiation-induced failures. Perhaps one of the few software crashes of unknown origin that have occurred were radiation-induced, but such software failures have been so infrequent they have been hard to characterize. Single-event upsets have been observed in the various computer memories but they have been handled by hardware EDAC and software memory wash as already described.

Apart from the radiation tolerance experience with ICs, AMSAT has found that solar arrays have degraded more slowly than predicted by industry-standard models.

Cooperation with Educational Institutions

AMSAT-NA has sought to establish partnerships with educational institutions to assist in some of its satellite projects. In this regard, a most productive relationship has evolved with the Center for AeroSpace Technology at Weber State University in Ogden, Utah (7).

The concept of building low-cost satellites is not new at Weber State (17). In April 1985, Nusat I was launched from a get-away-special (GAS) canister on the NASA orbiter Challenger. Nusat I operated nominally for 20 months until it burned up upon reentry. The cash outlay for Nusat I was less than $20,000 (1). In 1988, Weber State agreed to manufacture the major mechanical components for the AMSAT-NA Microsat project. One of the four satellites built as part of the Microsat project (WO-18) is owned and operated by Weber State and includes an earth imaging experiment designed and built by a Weber State team.

About the same time the Microsat project was under way, AMSAT-NA was investigating the feasibility of building a geostationary spacecraft called Phase IV. The help of Weber State was enlisted with this project also and a prototype structure was completed in June 1990. Additional work on antenna structures and deployment techniques was completed by spring 1991. Even though

work on the Phase IV project was terminated due to lack of sufficient funding within the amateur radio community, the work on the Microsat and Phase IV projects has served to refine the management interfaces and procedures between Weber and AMSAT-NA.

Weber State is making a very significant contribution to the AMSAT Phase 3-D satellite now under construction, by building the entire flight model spacecraft structure, the electronics module boxes, and the cylindrical section that will enclose and support the satellite on the launch vehicle (14).

Current Trends

While AMSAT has developed philosophies and procedures that have resulted in many successful missions, similar mixtures of fiscal, project, and personnel management procedures are becoming more sought after. In a recent article (2), Robert F. Crabbs has the following to say:

> *As it was at the outset, the future of the U.S. space program—civil, military, and commercial—lies in the hands and minds of the current generation of under-graduate, graduate and post doctoral students. If these people are not trained correctly, do not have appropriate role models, and do not develop a passion for doing space research, the United States' program will fall in decline and we will become a second-rate space nation...*
>
> *Launching 20 small satellites a year at a total cost of $100 million, with four or five total failures, will still provide a huge science return for our money, and maybe even greater than if we had built one large spacecraft for the same $100 million. We will have trained more students, employed more people and generated a lot more ideas while solving a lot of problems...*
>
> *Passion is what makes it all work. Without passion, thousands of people merely go through the motions on a daily basis. With passion, real solutions to problems are developed, innovation is generated, excitement builds, fears are overcome and visions develop.*

Without a doubt, the passion Crabbs talks about is a huge factor in the amateur radio space program.

It is interesting to note that until the past five years or so, there have been relatively few university-based satellite projects, but this is rapidly changing. Some of the projects currently underway are: SEDSAT at the University of Alabama at Huntsville (18, 19, 20); ASUSat at Arizona State University (6, 15); and the SQuiRT microsatellite program at Stanford (11, 12, 13). Other projects are in progress abroad. The origins of some of these projects can be traced very directly to the amateur radio satellite program either by virtue of their leadership or through study of principles and practices already developed by AMSAT organizations throughout the world. It would appear that the value of small satellite projects in the training of future engineers and scientists is becoming more widely recognized.

This paper has shown the evolution in complexity of amateur radio satellites from those able to operate for just a few weeks on battery power to the AO-16 Microsat that has been discussed in detail. Readers should pause to

contemplate the significance of a project like AO-16, which has been providing routine store-and-forward communications service for several years, while remembering that a parallel commercial service has not been developed in spite of many would-be service providers. Furthermore, it is important to note that the Microsats were developed from initial concept to launch in 25 months.

More important than any single cost-reduction strategy, what AMSAT hopes to offer is the encouragement to further develop and apply some of the AMSAT philosophy. Multiple-satellite systems, by virtue of their redundancy, can afford to implement different design philosophies than have been used in "all things for all people" single satellites. If the time has not been right for the adoption of new ideas before, perhaps the time for new ideas is closer. As the history, case study, and project management techniques are reviewed, it should be remembered that the goal of AMSAT's satellite projects is the enhancement of amateur radio communications through facilities provided in the Amateur Satellite Service. The volunteer nature of the service and the participating organizations and personnel dictate from the start that radically different procedures and techniques be employed. Clearly, the procedures and techniques that have been developed have resulted in many successful missions.

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Resources for NASA Managers

by Dr. William L. Lawbaugh

Book Reviews

Serious Creativity by Edward deBono. New York: HarperBusiness, 1992.

"Using the Power of Lateral Thinking to Create New Ideas" is the subtitle of this "step-by-step approach to creativity on demand." As such, it is based on Dr. deBono's earlier works, *Lateral Thinking* (roughly defined as a paradigm shift, or exploring multiple approaches in problem solving) and *Six Thinking Hats* (intuition–red, cognition–white, desire–yellow, inhibition–black, logic–blue and creativity–green hat).

DeBono makes six main points in this 338-page paperback. Point one: Creative thinking is vital in this age of cost consciousness, downsizing, continuous improvement and quality awareness. The old method of searching for and removing the cause of the problem does not always work. Creative solutions are in order.

Point two: Just because we can recognize creative solutions as logical only in hindsight, logic is not enough. Nor is a "crazy" solution, such as release from inhibition or the group dynamics of brainstorming (point three). Rather, creative thinking is serious, and, with the proper tools and techniques, can be executed systematically, without waiting for inspiration or genius (point four). The primary "lateral thinking tools" deBono discusses are challenge, alternatives and provocation.

Creative challenging is inquisitive, asking "Why?" and searching for viable alternatives. DeBono blames the current morass in U.S. industry on the old saw, "If it ain't broke, don't fix it." Rather than merely problem-solving, managers ought to be questioning, challenging the status quo. They should also beware of "lock-in" or other people's requirements. For example, the standard QWERTY keyboard was invented for Underwood typewriters, to slow down the sequence of common letters so the keys would not stick together as often. Managers can break free of complacency ("We've always done it this way") and rut-thinking (either/or polarities) by lateral thinking—seeking fresh ideas, alternative routes, challenging old assumptions.

Provocation is a more difficult concept, variously defined as temporary madness and as "po," a term deBono says he created in 1968. "Po" is extracted from sup(po)se, (po)ssible, hy(po)thesis, (po)etry, (p)rov(o)cation, or (p)rovocation (o)peration. Provocations can "arise" or they can be induced by asking "What if?" or "Suppose . . ." For example, deBono says he imagined: "Po, the police have six eyes" for *New York* magazine in 1971 in response to the city's crime problem. From that po came the suggestion that neighbors could serve as the eyes (and ears) of the police, evolving into today's "Neighborhood Watch" programs, he says.

This sounds a lot like brainstorming, which deBono deplores, or free association or merely

use of the brain's right hemisphere. Po also resembles the poet T.S. Eliot's concept of "dissociation of sensibility," which he described nearly 70 years ago as the "willing suspension of disbelief."

DeBono's fifth and sixth main points deal with the implementation of serious creativity. "The successful organizations of the future," he asserts, "are those that have already begun to think differently." However, lateral thinking is not enough. It must operate hierarchically: "There is a need for someone senior to have responsibility as a 'process champion'; otherwise, not much will happen," he says. Such is the case with David Tanner, who set up DuPont's Center for Creativity, and Ron Barbaro, who gave Prudential the ideas for living (catastrophic) benefits and the reverse mortgage. Both men, incidentally, hired deBono to run inhouse lateral thinking seminars and workshops to train trainers, all services dutifully footnoted, with fax numbers, throughout the book. While serious creativity and lateral thinking are designed for individuals to create new ideas, deBono adds a section on the application of these techniques for large groups and organizations. The institutionalization of creativity may seem a contradiction in terms, but the use of lateral thinking has already proven useful in organizations that seek to reinvent or reengineer themselves.

Managing at the Speed of Change by Daryl R. Connor. New York: Villard Books, 1993.

Daryl Connor describes himself as "an entrepreneurial-based researcher...of a single phenomenon—the human response to organizational change." Change is rapid today, and to manage at the speed of change requires "resilience," a blend of strength and flexibility.

Even the nature of change is changing, says Connor. It increases in volume, momentum and complexity. These are the "good old days," for in the future the world will appear far more fragmented, dizzying and disorganized than today. We will greet this new world with stress, future shock or resilience.

Connor identifies eight patterns believed to be most critical in the successful management of major organizational change:

1. Assimilate change at the speed of change.
2. Initiate certain changes, for timing is everything.
3. When the going gets tough, permit and accept the inevitable pain.
4. Be ready, able and willing to apply the skills of adapting to change.
5. Commit intellectually and emotionally to the cost and duration of change.
6. Realize how powerful corporate culture can be in resisting change.

The seventh pattern is "synergy" to which Connor devotes two full chapters. In self-destructive relationships, such as a messy divorce or bankruptcy, one plus one equals less than two, but in synergistic teamwork,

resilient people gain energy during change rather than feel depleted by it. Employees are empowered by synergy, rather than exploited or victimized; participative management becomes more powerful in dealing with change. Connor even recommends Edward deBono's concept of "lateral thinking," a shift from linear or logical thought to lateral or analogic-based thinking to meld divergent viewpoints.

Pattern eight is "resilience" again—personal, organizational and social—in the crisis (or opportunity) of change. The truly resilient managers view life as complex but full of opportunity; have a clear vision of what they want; show remarkable flexibility in response to uncertainty; develop structural approaches to the management of ambiguity; and they proactively engage change rather than defend against it.

Connor ends his book with a plea and a warning. As changes accelerate exponentially, resilient managers are needed more than ever. "By approaching change in a disciplined manner, we can be architects of our future." If not, we pay the price.

Leadership and the Computer by Mary E. Boone. Rocklin, CA: Prima Publishing, 1993.

"When properly applied, the computer can serve as one of the most powerful leadership tools ever invented," says Mary Boone. To prove it, she garnered research grants from four computer companies and went out to interview CEOs at Tootsie Roll, Mead, PanAm, Manville, Aetna, Mrs. Fields' Cookies and half a dozen others, including Senator Gordon Humphrey (R-NH) and the CEO of The Cable Guide. Her conclusion: "Computers give executives the opportunity to empower or oppress."

Of course, Ms. Boone, a management consultant in Ridgefield, Ct., hopes that computers will be used to empower, liberate and enhance the skills of the work force. She describes, in a series of interviews, how computers can help executives to:

- Stay well-informed by tapping directly into internal and external databases, the electronic equivalent of Tom Peters' management by walking around.

- Communicate more effectively through electronic mail, improving access and even encouraging what Warren Bennis calls "backtalk" and dissent.

- Manage time better by not only speeding up responses but also working regardless of time and place, what Peter Drucker calls achieving control of what little time can be controlled.

Boone says computers can also help to shape or change culture, coach workers and enrich personal thinking through expert systems, modeling, calendars and bulletin boards. She does not mention forums or online discussion groups to gain fresh ideas and outside perspective, but she does mention a number of word processing tools (like spellcheckers, translators and thesaurus) to improve critical communication skills. She mentions but does not develop the

notions of programmed learning and computer-aided instruction.

Boone is best when she answers the excuses most managers give when asked to make use of computers. When they see how computers give them greater control of information they need, managers no longer say they are too old or set in their ways. Some can't even type, but Boone points out that many CEOs "hunt and peck" or play with the computer's mouse. As for the mindless aspects of computer hacking, Boone offers eight good reasons why doing it yourself is more efficient than being dependent on staff for every little thing.

When Mary Boone wrote *The Information Edge* with Dean Meyer in 1989, she discovered that most executives used only one tool of the computer, say spreadsheets or conferencing. In just five years she found them experiencing "the headiness, the freedom, and the boost to intellectual power that computer and communications tools can provide." When the computer is regarded as more than a mere administrative tool, it will take its place among and possibly replace other management tools such as meetings, reports, speeches and the telephone. Until then, the computer will be regarded by some as a very expensive calculator, typewriter or filing cabinet. Boone suggests it can enhance leadership in virtually any organization.

Working Without a Net by Morris R. Schechtman. Prentice Hall: Englewood Cliffs, NJ, 1994.

"How to Survive and Thrive in Today's High Risk Business World" is the subtitle of this timely book. The author says "we must learn to work with change, not deny it. And with our safety nets gone and our external props kicked away, we must learn to work together in new ways while we find sources of stability within ourselves."

The old work assumptions called for blind loyalty in exchange for job security, the result amounting to mediocre job performance and conflict avoidance. These assumptions are rapidly giving way to loyalty to quality and finding security in self instead of the workplace, resulting in peak performance and embracing change as a choice.

Morris Schectman is, ironically, a consultant to the insurance industry, the paradigm of safety nets. Nevertheless, this former ghetto schoolteacher and trainer of street police in Aurora, Il., learned much about high risk work and writes eloquently about the management of change.

He makes a sharp distinction between caring for people and caretaking, the latter described as destructive to organizations and hostile towards employees. TQM requires workers to transform themselves, "from good soldiers to challenging employees." Self-esteem is necessary for change; if you feel good about yourself, you don't need a safety net. Peak performance is possible only when people feel passionate about their work. Yet, a worker's personal or home life can adversely affect or

enhance peak performance. And finally, personal values must blend with core, institutional values. If not, take a walk, he suggests.

Working without a net seems like jungle ethics, survival of the fittest, change for change's sake, foolhardiness. Schechtman believes we live in a high-risk culture, that stress is a positive, activating force (as opposed to distress), and that life is at its best when we grow, learn, change and make a positive impact on the lives of others.

Integration of personal and professional life, of personal and institutional values is a start. But what about managing the lives of others? Schechtman suggests the same kind of push and drive. After all, no coach ever told Michael Jordan to slack off, to do whatever he wanted because he's a nice guy. Nor would we obey speed limits or pay our taxes if we were not held accountable. "Conflict isn't negative," says the author. Nor is anger, as long as it's expressed in terms of personal disappointment. Both generate peak amounts of productive energy. As for loyalty, the author compares it to patriotism, which allows for constant challenge and confrontation at times.

In sum, *Working Without a Net* is a stimulating, creative work. The author includes a "Value Clarification Instrument," a 10-question quiz that underscores his points about inner security and management of others. Even if the reader flunks the quiz, Schechtman offers compelling reasons to clarify if not change one's core values about work in a high-risk culture.

The Human Element: Productivity, Self-Esteem and the Bottom Line by Will Schutz. San Francisco: Josey-Bass Publishers, 1994. *Reviewed by David LeSage, Chief, Executive and Management Development, NASA.*

If your boss seldom meets with you and other members of your project team, she possibly has low Inclusion needs. If, when you are given an assignment, you enjoy the freedom to organize the personnel and resources to get the job done as you see fit, you possibly have high Control needs. If your office colleague frequently shares his feelings as well as his thoughts about issues, he is probably high on Openness.

Inclusion, control and openness are the three fundamental interpersonal behaviors which help explain and predict most other interpersonal relations. That was one result of Will Schutz's original research in the early 1950s. At that time he was asked to identify compatibility factors for combat teams in large warships.He continued his career in the scientific field for another 20 years. The next milestone in his own personal development came when he was doing research with a psychotherapeutic group at the Massachusetts Mental Health Center. He recalls:

> *As a group member I was admonished to tell the truth, hear feedback from others about how they really felt about me, and open myself to the world of feelings...a frightening delight. Groups became a source of intellectual knowledge and of personal growth. I became fascinated by them, a fascination that continues to this day.*

The next decade was spent developing his "human element" approach to life, where he integrated his scientific knowledge with a depth study of "feelings." Understanding the three basic behaviors of Inclusion, Control and Openness increased with the discovery of parallel underlying feelings of Significance, Competence and Likability. As it exists today and detailed in his latest book, "The Human Element is a holistic, overarching model that presents an integrated approach to all the human issues in an organization."The tenets of the Human Element model are:

- TRUTH. "Truth is the grand simplifier. Relationships are greatly simplified, energized and clarified when they exist in an atmosphere of truth."
- CHOICE. "I choose my own life—my thoughts, feelings, sensations, memories, health, everything—or I choose not to know I have a choice."
- SIMPLICITY. "The most profound solutions are simple. Simplest is best."
- LIMITLESSNESS. "Human beings have no limits to their potential. Our only limits are limits of belief."
- HOLISM. "All aspects of a person (thoughts, behavior, feelings and the body) are interrelated."
- COMPLETION. "Effectiveness and joy are enhanced by the completion of unfinished experiences."
- DIMENSIONS. "The basic dimensions of human functioning are inclusion, control and openness."
- SELF-ESTEEM. "All behavior derives from self-esteem."

Because of the centrality of self-esteem, much of Will Schutz's human element is really a "well-tested theory and methods aimed at helping you increase your self-awareness, self-acceptance and self-esteem, and thus realize your full human potential, both individually and as a member of a group." In a sense, this book is really about empowerment, self-realization and being all that we can be.

At the opposite extreme of self-esteem is what he calls "self-deception," not being self-aware. Not being aware makes us susceptible to being dominated by our defense mechanisms and becoming "rigid," inflexible, acting in ways we don't understand, often not liking what we are doing, and frequently resulting in ineffective interpersonal relationships. In this sense, Schutz makes a very bold statement:

> *Teams do not fail because they disagree, or because they do not have common goals, or because their members' approaches to solving problems differ, or because they do not include certain personality types. They don't work because one or more people are rigid, and a person is rigid because his or her self-concept is threatened.*

Will Schutz's belief, and my experience in conducting Human Element workshops, is that as individuals gain self-awareness and self esteem, they become more open and honest with their coworkers. They redirect

the energy they once used for defensiveness, withholding and interpersonal struggles into productive work.

An example of this is what Schutz calls "concordant decision-making." Described as "with the heart" and going beyond what we know as "consensus," concordant decision-making is an extension of the Inclusion, Control and Openness behaviors. In concordant decision making, those who are Included are those who know the most about the content of the decision and those who are the most affected by it; every person on the decision-making team has equal Control or power, and everyone has a veto; and everyone is required to be Open and honest and express true feelings about the decision. To put this openness to the test, every individual must be able to utter a "yes" or "no." A "yeah" or "OK" is a sign of some hesitancy, is considered a "no" and requires further discussion.

As the subtitle of this book indicates, *The Human Element* is about developing self-esteem through self-awareness. Self-esteem leads to more open communication with colleagues, which ultimately affects productivity and the bottom line.

To gain maximum benefit from the book, Schutz suggests you read it through once, quickly. Then start again, and take one small piece at a time. Respond completely and honestly to the "Pause for Reflection" sections. Then read through the whole book once again. "You will probably get much more from it this time," Shutz says. I agree. Better still, come to one of the five-day workshops NASA makes available to you. Let either this book or the workshop be your next step in developing your own self-awareness, self-esteem and greater self realization. Hundreds of NASA managers and employees have already started the journey.

The Human Element Workshop

Will Schutz has designed a five-day workshop to enable participants to experience increased self-awareness and self-esteem as described in his most recent book. The workshop is interactive and experiential, but very well structured. Maximum benefit is gained when individuals attend with one, two or more coworkers. The topics covered include:

- **The overarching concepts of Truth and Choice as problem-solving tools for understanding human behavior**
- **The interpersonal behaviors of Inclusion, Control and Openness**
- **The underlying interpersonal feelings of Significance, Competence and Likability**
- **The behaviors and feelings applied to the self: the Self-Concept and Self-Esteem**
- **Defense mechanisms**
- **Health and illness: the mind-body connection**
- **Team compatibility and work relations (this is where work teams benefit most)**
- **Concordant decision-making**

Workshop methodologies include lecturettes, self-assessment instruments, guided imagery, feedback and non-verbal activities. The workshop is offered twice a year at Wallops for Agencywide participation, and as often as can be scheduled at a Center, so that more people from one workplace can attend. The workshop was originally introduced at NASA in 1983 as a follow-on to the Management Education Program and Senior Executive Program, it has since been available to the entire NASA work force, with emphasis on people attending with work colleagues, and attending voluntarily. For further information, call David LeSage at NASA HQ, Code FT (202)358-2183 or Ed Hoffman, NASA HQ, Code FT (202)358-2182.

Video Reviews

Explorer Satellite Program: Shared Experiences with Gerald Longanecker, Goddard Space Flight Center, September 1989.

In response to Soviet domination of the space race, the Explorer Program began on January 31, 1958 with the much-heralded launch of Explorer One. In the next three decades, more than 75 Explorer class missions would explore black holes, supernova and astronomical phenomena.

Gerald Longanecker, project manager on some half dozen Explorer missions, introduces this 30-minute film, produced by Manfred "Dutch" von Ehrenfried for Technical and Administrative Services Corp. (TADCORPS) with field production by Karen Igo and Goddard Television.

Project Manager Jerry Madden explains the first of three explorer projects, the International Sun-Earth Explorer (ISEE). From 1971 until launch in 1978, Madden worked with counterparts in the European Space Agency (ESA) to build three ISEE spacecraft carrying 20 distinct experiments. In dealing with Europeans, Madden found his Goddard team had to come early and stay late for meetings with ESA. Most items of business had to be agreed to before the actual meeting, and each side was expected to go over the meeting's action items, rewriting them for clarity if necessary. Parts problems and testing proved most challenging, but this Explorer project came in on time and on budget, "a total success."

The Active Magnetospheric Particle Tracer Explorers, begun in 1981 and launched in 1984, involved three nations, three spacecraft and three very different management styles. NASA Project Manager Gilbert Ousley describes working with counterparts from the Federal Republic of Germany (then West Germany) and the United Kingdom, the British space agency. Here the major change involved a shift from launch on a Delta rocket to the Space Shuttle, meaning a radically different flight path and orbit for AMPTE. Ousley found that resisting change is not as productive as using change to increase the science return of a spacecraft while sharing the pain of engineering. Like Jerry Madden, he found it helpful to meet privately with his European counterparts before a formal meeting, and respect one another's management methods without trying to standardize all procedures. As a result, AMPTE flew for five years, providing an abundance of data and research about the movement of particles in space.

Deputy Project Manager Don Margoles described the Extreme Ultraviolet Explorer (EUVE) mission, about to be launched then. EUVE was the first spacecraft to be serviced simply and changed out by the Space Shuttle under GSFC's Equipment Acquisition Plan (EAP) and the new Satellite Servicing Project. Under these arrangements, EUVE depended upon existing hardware as much as possible, a reusable bus and Government Furnished Equipment from other projects. EUVE involved NASA, industry and academia: Goddard, Fairchild and the Space Sciences Lab of the University of California at

Berkeley. The spacecraft was originally designed for the Space Shuttle and then capable of the ferry of a Delta launch. Margoles stresses flexibility as much as possible in meeting requirements and calls EUVE a "trailblazer for the future."

Dr. John Townsend Jr., then Director of Goddard Space Flight Center, closes out this video with commentary on the Explorer Program. He shows how GSFC became a "smart buyer" by having Goddard people on top technically, although he noted the Center had trouble retaining some of their best people. However, the many Explorer projects were on the cutting edge of technology and versatile enough to put aside for crisis efforts or emergency programs. He added that the Explorer projects over the previous three decades proved most beneficial for inhouse instruction, becoming "a training ground for future project managers" in NASA and industry.

Award Fee Contracting with Murray Weingarten of Bendix Field Engineering Corporation, October 5, 1989.

Murray Weingarten is past chairman and president of Bendix, considered the pioneer for award fee contracting between NASA Goddard Space Flight Center and Bendix since the early 1960s. Joe Engle, his successor at Bendix, opens the 35-minute video with an overview of the company: 7,000 employees in 120 locations and 20 countries with $450 million annual revenue from 200 contracts. Half of Bendix's work is with NASA, and 80 percent of that work is under award fee contracts. Engle says at that time, 1989, half of NASA employees were contractors and 88 percent of the NASA budget was spent in procurements.

Weingarten starts off by saying it is easy to measure performance in hardware, but not easy to measure "service." The common Cost Plus Fixed Fee (CPFF) contract worked fine for the uncertain Mercury projects with its standard 5 percent pre-tax fee, but Services involved more subjectivity and disputes. In spite of rumblings from the Bendix legal staff, Weingarten proposed a Cost Plus Award Fee of 3 to 7 percent with GSFC. The government was given unilateral rights to award the fee, not subject to dispute from the contractor. Thus began "Award Fee Contracting in the Service Industry," resulting in outstanding performance and win-win for both sides.

However, Weingarten warns, the Award Fee process can mean more work for both sides. The "performance evaluation system" for one contract took 10 workyears of effort in just one year. But, it was worth the extra effort because both sides were forced to communicate with each other. He recommends both sides establish mutual objectives every quarter or trimester at least.

"Where do we want to be in three months?" he asks. "You become partners if you know what you want to accomplish." At each quarterly review, top management of both sides will want to measure the accomplishments or study the reasons for failure to meet the agreed-upon objectives fully.

Weingarten also warns against simmering complaints or disappointments. He urges both sides not to wait until the quarterly or trimester review to air problems or concerns. Contractors hate the "I gotcha" surprises and "bitch list" evaluation letters. Top industry management will want to keep government happy and focus on problem areas.

Under the old CPFF arrangement, people are too busy to talk with one another, evaluate and measure. But under the CPAF, Weingarten says, both sides are forced to talk and raise performance levels. It also has built-in motivation and incentives, he notes.

Management Issues in Manned Spaceflight with Aaron Cohen, Henry Pohl and Joseph P. Loftus, Jr. at NASA Johnson Space Center, December 7, 1989.

This video, also a part of a series in the NASA Program/Project Management Initiative (PPMI) collection, features three legendary managers from Johnson Space Center. Past Center Director Aaron Cohen leads the discussion of management issues at JSC, accompanied by Henry O. Pohl, Director of Engineering at JSC and narrator Joseph P. Loftus, Jr., Assistant Director of Plans at JSC.

"Keys for success" open and close this 55-minute discussion, followed by 25 minutes of questions and answers over NASA's interactive video network system. All three agree with Cohen, who says there is no substitute for early hands-on experience, especially with hardware or analysis, for prospective project managers. Later on, Cohen adds "good formal education" and a variety of personal qualities, such as patience, integrity, honesty and the ability to communicate clearly up, down and laterally.

As for major changes he has seen over the years at NASA, Cohen says it was clear in the Apollo era that performance came first, then schedule and cost. In the Shuttle era the order shifted to performance, cost and schedule, and while it is too early to tell (in 1989), the Space Station era may be characterized by cost, schedule and performance, in that order. Pohl added that it wasn't an abundance of money in Apollo days, but "flexibility" that made the difference, less external oversight, second-guessing and control.

What about JSC's organizational culture? Both agree that the Center's matrix organization is open to interactive decision-making. Cohen calls it "participative management" and Pohl calls it "collegial." In large, complex programs, no single person has all the answers so the project manager is attentive but decisive, with "51% of the vote" for a firm, timely decision on changes. The first change pitfall will be cost overruns, which could lead to schedule slips and performance problems. "Engineers do not like to deal with budgets," Pohl observes.

What about the next five or ten years? asks Loftus. Cohen conceded that NASA was losing many seasoned Apollo veterans but he expressed hope in the college fresh-outs. Johnson will be challenged to maintain

technical excellence and train good people. Facilities and equipment (read: computers) will need constant upgrading. None of the panelists seemed to anticipate downsizing, reengineering or reinventing. Rather, Cohen says: "You can't afford failure," which is devastating and expensive. A final theme that runs through this fascinating video is the notion of teamwork, with both NASA personnel and contractors.

Pohl concludes the 120-minute of tape with the assertion that success or failure does not depend on the type of organization in NASA or at the Centers, but rather "the will of the people involved to succeed."

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